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Energy Security in ECO countries for 2020-2030 Periods

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Abstract. Energy security in the ECO is considered in the context of diversification of energy supplies and transport connectivity, taking into account the lack of access to the sea for most of the ECO member countries. Energy security is considered taking into account a set of influencing conditions, such as the dynamics of the global energy economy, environmental, economic, geopolitical and financial aspects. Ensuring energy security should be guided by interregional connectivity in the ECO region, which is improved through the implementation of some regional projects of global importance in various multilateral formats. Taking into account the different levels of development of energy infrastructures and the availability of fuel and energy resources of the countries of the region under consideration, the concept of ensuring energy security is substantiated, taking into account the formulation of regional energy security policy in a comprehensive manner by searching for synergies and complementarities between global, regional and national dimensions.

Keywords: Energy security, energy resource supply, climate change, …

1 Introduction

Energy security acts as a component of the energy trilemma, both in assessing the effectiveness of energy sector performance and in assessing its sustainability [1].

The actualization of the problems of energy security dates back to the 70s of the last century. Another military-political crisis in the Middle East led to an energy crisis - to a sharp decrease in the volume of exports of primary energy resources and to a manifold increase in prices for them. This led to the adoption by the industrialized countries (USA, Canada, Western Europe, Japan, etc.) of a number of radical measures to ensure energy security, including the creation of the International Energy Agency to coordinate these measures.

At present, an increase in energy consumption is observed all over the world [2]. We see this transformation of global energy consumption in Figure 1 below, which shows a graph of global energy consumption since 1963. This is due, on the one hand, to the high standard of living in developed countries, on the other hand, to the intensive growth of energy-intensive industries in developing countries. In these conditions, energy security acquires particular importance, occupying one of the key positions in the country's economic and national security [3, 4,5,6,7].

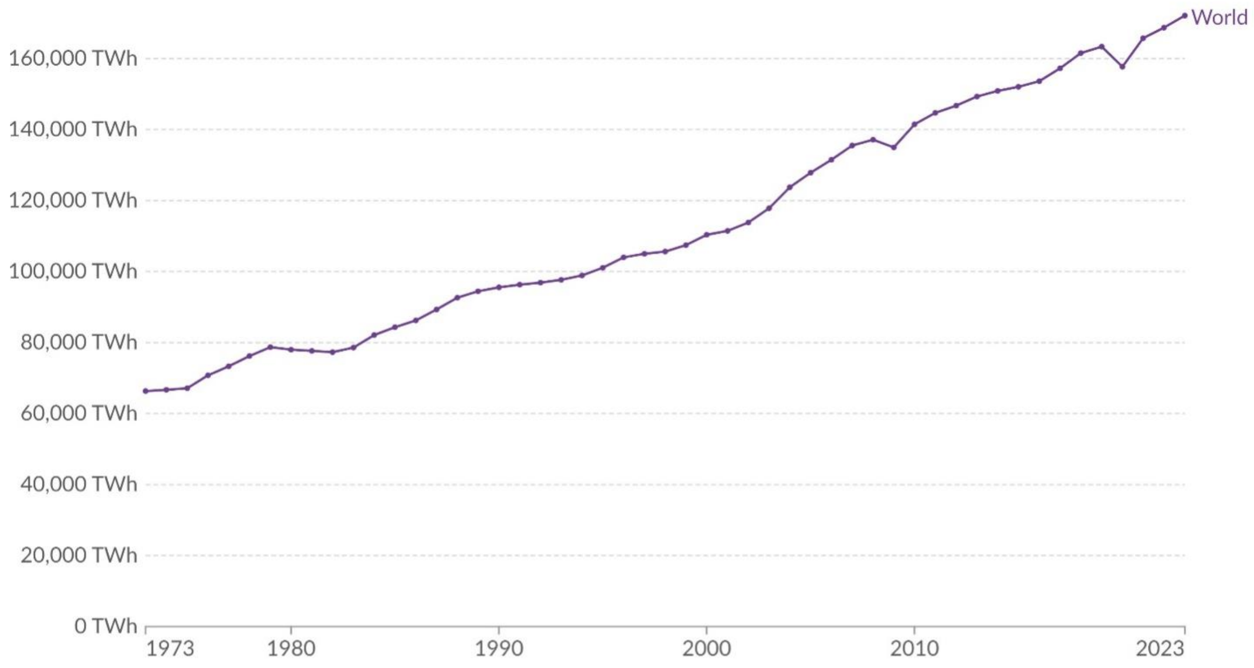

Fig. 1. Primary global energy consumption [2]

Note: Data includes only commercially-traded fuels (coal, oil, gas), nuclear and modern renewables. It does not include traditional biomass.

Energy security is among the priority areas of the Economic Cooperation Organization (ECO). "ECO Vision 2025" stipulates the enhancement of energy security and sustainability through wider energy access and trade as one of the ECO's major strategic objectives [3].

The energy orientations of ECO Member States are divergent given their development plans and levels, resource endowments as well as energy infrastructure. This divergence leads them to set national energy priorities and targets contrasting with each other. Developing regional goals and translating them into tangible steps relevant for all ECO Member States necessitate formulation of Regional energy security policy in an integrated manner by finding synergies and complementarities between global, regional, and national dimensions.

Never the less at the present new dynamics on the global energy landscape, particularly environmental, economic, geopolitical, and financial dimensions are getting national and regional levels thus creating challenges and opportunities to be addressed in line with new momentum.

Henceforth, ECO had to undergo the process of development of its fundamentally new Strategy on Energy Security.

The literature on energy security is however characterized by widely differing and sometimes inconsistent definitions of the concept. This is partly because various authors on the subject have tended to focus on different sources of risk and conducted studies that differ in the scope of the impacts of the various risks.

- Bohi and Toman [8, 9] define energy security as the loss of welfare that may occur as a result of a change in the price or availability of energy.
  - Cherp and Jewell [10] assert that energy security is an instance of security in general and define energy security as "low vulnerability of vital energy systems".

- Winzer [11] notes that energy security is commonly defined by incorporating the context. Thus, in the United States, the focus of energy security has traditionally been on the reduction of vulnerability to political extortion following the economic hardships experienced in the aftermath of the oil embargo by the Organization of Petroleum Exporting Countries (OPEC) in the 1970s. This is also the reason why policy makers in the United States strongly support the g oals of energy independence and raising the shares of renewable energy.
- Winzer [11] further notes that in several developing countries, the goal of energy security has been to protect the poor against commodity price volatility. He defines energy security as continuity of energy supplies relative to energy demand.
- According to Andrews [12] and Jun et al. [13], energy security means assuring adequate, reliable supplies of energy at reasonable prices and in ways that do not jeopardize major national values and objectives.
- Intharak et al. [14] define energy security as the ability of an economy to guarantee the availability of energy supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect economic performance. Their definition thus embodies three fundamental aspects, namely, physical energy security which is the availability and accessibility of energy supply sources; economic energy security which is the affordability of resource acquisition and energy infrastructure development; and, environmental sustainability which entails using energy resources in ways that meet the needs of the present without compromising the ability of future generations to meet their own needs [15].
- According toGrubb et al. [16] and Kruyt et al. [17], security of supply is a system's ability toprovide a flow of energy to meet demand in an economy in a manner and price thatdoes not disrupt the course of the economy.
- Sovacool[18–21], Sovacool and Brown [22], Sovacool and Mukherjee [23], Sovacool et al.[24], Brown and Sovacool [25], and Badea et al. [26] define energy security as equitably providing available, affordable, reliable, efficient, and environmentally benign energy services to end users.

Although the definitions of energy security provided above are not exhaustive, they all illustrate the importance of energy security, its multi-dimensional nature, and why many countries regard it as a policy priority. In the short-term, energy security concerns focus on the ability of the energy system to react promptly to sudden changes in the supply–demand balance. In the long-term, energy security concerns have to do with timely investments in energy supply in line with economic developments and environmental needs. At the multilateral and global levels, energy security has continued to receive increasing attention as evidenced by Sustainable
Development Goal 7 of the United Nations that requires countries to ensure access to affordable, reliable, sustainable, and modern energy for all.

Despite the numerous studies to assess energy security, characterizing its various aspects, a number of conceptual problems of a theoretical and methodological nature have not yet been resolved.

1. ENERGY SECURITY of ECO region

In its fifth decade of existence, ECO's potential for advancement of regional energy agenda still remains untapped and requires focused attention by all stakeholders. Diversification of source of

energy and energy connectivity plays a fundamental role in the ECO Region taken the unique geostrategic location and land-locked status of the majority of ECO Member States. ECO's energy mix is composed largely of fossil fuels, which account for almost 94% (*see Figure 1*).

In the ECO Region, the already very high dependence on hydrocarbons (see Figure 5) to satisfy the rapidly growing demand for electricity, heating and transport services is ever growing. The volatile prices for fossil fuels remain an energy security concern for both the countries with high import dependency and net hydrocarbon exporters. More efficient energy systems are highly desirable for economic competitiveness, low-carbon intensity, and reliable and affordable energy services to consumers. Financing decisions to be taken in the energy sector in this region will highly impact global climate change mitigation and adaptation efforts. According to International Energy Agency statistics, during 2016-2018 data, total volume of CO2 emissions of ECO region was 1583mt which is about 4,8% of total share of the world. Though the amount was not considered as a troublesome, few ECO Member States are increasing emitters of GHG and will play an important role to achieve the commitments of the Paris Climate Agreement.

Due to its geographical location, the region is also vulnerable to climate change impacts. In recent decades there has been an incidence of extreme weather events, which have been affecting the life of people, property and overall development of the countries; leading to people moving across borders due to climate-related consequences. Therefore, the climate change-related aspects and Paris Climate Agreement should to be focused while addressing sustainable energy agenda in the ECO Region. The greening of the power sector through the rapid deployment of renewable energy and acceleration of energy efficiency is a key in formulating a climate change responsive approach to energy sector planning in the ECO region.

Consequently, the reuse or recycling of natural resource inputs; enhancing production and consumption of renewable sources of energy; preservation of critical (or non-substitutable) natural capital; and minimizing pollution and other environmental impacts – including greenhouse gases (GHG) emissions – will be key vision to guide by ECO Secretariat. At the same time, best practices will be sought to open wider discussions for the policy measures to encourage broader socio-economic objectives including economic growth, equality, employment, health and wellbeing, and poverty reduction.

The ECO Region predominantly represents a set of inadequately connected and isolated energy markets lagging behind its huge potential. However, intra- and inter-regional connectivity in ECO Region is being diversified thanks to the large-scale energy and transportation infrastructure projects under different multilateral formats.

It is noteworthy that trans-boundary infrastructure networks can help increase energy security, reduce vulnerability, and cooperation should help develop energy solutions and ensure environmental protection of cross-border resources and ecosystems. Regional energy cooperation will also facilitate better energy connectivity which in turn will have spillover effects and increase access to services such as education, health and housing as well as electricity and markets for marginalized populations.

The key drivers of the energy security shall be the launching of the domestic energy market, enhancement of energy connectivity and diversification of the energy mix of the overall ECO Region.

Ensuring energy security in the ECO Region requires the integrated and coherent approach, including via providing support to nurturing behavioural change towards more efficient energy consumption, capacity building and awareness raising, etc. Further development of national

legislations and harmonization of legal and regulatory frameworks in Member States is a crucial factor to achieve energy security. Energy trade is one of the critical elements that can greatly contribute to enhancing energy security both within the sub-regions and the entire ECO Region.

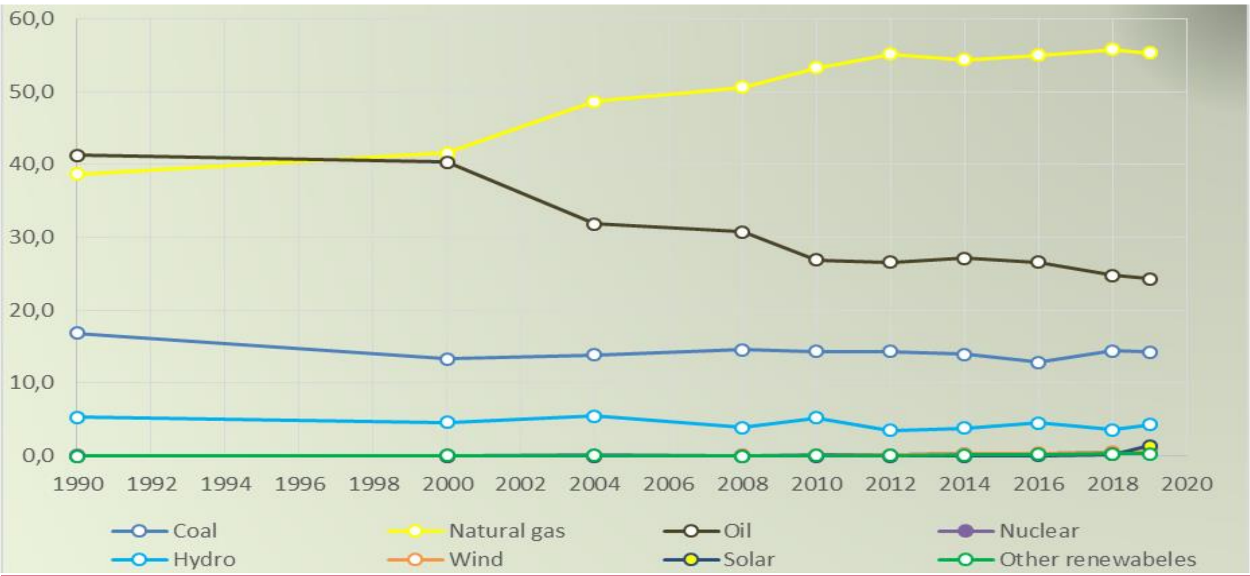

Fig 2. Share of energy consumption by source, ECO region, %: *Source: Our World Data on BP Statistical Review of World Energy (2020)*

Ensuring energy security in the ECO Region requires the integrated and coherent approach, including via providing support to nurturing behavioural change towards more efficient energy consumption, capacity building and awareness raising, etc. Further development of national legislations and harmonization of legal and regulatory frameworks in Member States is a crucial factor to achieve energy security. Energy trade is one of the critical elements that can greatly contribute to enhancing energy security both within the sub-regions and the entire ECO Region.

2. Enabling policy environment and upgrading the regulatory framework

Having recognized that to address challenges and opportunities stemming from national priorities to meet needs of energy and technology transition as well as to respond to Global trends in SDG7, capability of energy related institutions to provide appropriate policy and regulatory environment will play crucial role. To reach particularly at regional level, necessitates collaborative approach. For the sustainable, reliable and resilient energy market in ECO space, institutional framework and broad reform agenda in energy are of utmost important.

Notwithstanding from exclusive national interests, ECO Member States enjoys high level political and good neighbourhood relations, which is one of the core values to maintain and further enhance regional energy cooperation under this Strategy.

Sustainable, equitable and affordable energy requires more interconnectivity, efficiency and cost-effectiveness to achieve energy security favouring consumer satisfaction. It does so by developing and providing frameworks, good practice guidelines, standards and statistics to help measure progress. Good practices from Member States, the private sector, research and academia, as well as relevant circle of international community will be collected and shared back with Member States.

Transformation of energy mix towards meeting the needs in the ECO Member States through cooperation in the regional level and responding to the priorities in the global level must be in compliance also with appropriate enforcement mechanisms.

1. Enhancement of energy connectivity and its role in establishment of economic corridors

ECO represents the heterogeneous region, where the recent population growths, economic and industrial development, as well as the climate change have started to pose challenges to traditional development strategies of the ECO Member States. The success of social and economic development strategies in the ECO Region evidently depends on future investments in energy infrastructure and services. The volatile prices for fossil fuels remain an energy security concern for both the countries with high import dependency and hydrocarbon exporters in the ECO Region.

The abundance of energy resources and favourable geostrategic location of ECO Region as a whole are built-in regional advantages making ECO Region more competitive vis-à-vis neighbouring and other regions. In the ECO Region, Iran, Kazakhstan, Azerbaijan, Turkmenistan and Uzbekistan are rich in fossil fuels, whereas hydropower resources are concentrated in the mountainous Tajikistan and Kyrgyz Republic. ECO Region is geographically located to trade both surpluses and periodic shortages externally. In fact, the energy supply and demand balance in the region is such that trade is an obvious and in the near term, the only path to unlocking the value of its significant energy resources. Turkey, Pakistan, and Afghanistan heavily dependent on hydrocarbons as net importers, likewise they are doomed to be important energy transit countries.

The detriments of the low pace and magnitude of cooperation within ECO are most evident in energy and transport connectivity although they have always been priority areas of our collaborations. With this in mind, the multi-vector connectivity, most notably supporting development of a reliable network of interconnectors in the ECO Region features as a strategic dimension of cooperation within ECO in the context of "ECO Vision 2025". Greater stability, security and reliability of energy supply and demand in the Region; energy trade and transit to increase economic value, and energy security within and beyond the Region are among the policies ECO is pursuing under the current arrangements.

Diversification of energy supply and transport connectivity plays a fundamental role in our region, considering this unique geostrategic location as well as the land-locked status of the majority of the ECO Member States. Intra- and inter-regional connectivity in ECO Region are enhancing through implementation of some regional projects with global importance under different multilateral formats. This is where ECO Member States have found critical mass of common interests. There are also ongoing pipeline and transport projects in the ECO Region at feasibility study to construction stages aiming at diversification of connectivity beyond ECO framework.

Maximizing connectivity, mobility and accessibility by making major ECO transport corridors commercially viable and operational, and transformation of the selected transport corridors into a sort of economic corridors that would integrate transport, energy, telecommunication and other links in the long-term perspective are among the policies ECO is pursuing under the current arrangements. Ample opportunities hence exist to upgrade our region into an energy hub through consolidated efforts. With this in mind, ECO is currently engaged in promotion of the East-West, North-South and South-West transport corridors.

ECO Region is the nest of many energy infrastructures and capacities onshore and offshore. Interconnectivity among the abovementioned capacities should be considered deeply. Pipelines

among the Member States also play a key role on energy movement. Gas pipeline from Iran to Turkey, Turkmenistan-Afghanistan-Pakistan-India gas pipeline (TAPI), Turkmenistan-Azerbaijan Trans Caspian gas pipeline, Iran-Azerbaijan swap of gas by pipelines for sending to Nakhichevan, Iran-Pakistan-India gas pipeline, and oil products pipeline of Iran-Afghanistan border are major carriers of energy among the Nations. The abundance of energy resources in one hand and big markets for consumption in another hand, create a complimentary economy for Member States. For example, designing a loop between gas resources of southern Iran, Pakistani market, TAPI, Turkmenistan, Azerbaijan, and Trans Anatolian Gas Pipeline (TANAP) should create a loop of cooperation and high trade-offs among the ECO and beyond.

ECO Secretariat is working on the concept of "ECO Economic Corridors (EEC)". The energy sector of EEC should connect the infrastructures, maritime routes, and pipelines in broader geographical region in three major continents.

In sum, the Strategy focuses on the multi-vector connectivity, most notably supporting development of a reliable network of interconnectors in the ECO Region.

2. Strengthening the role of the ECO Region in global energy architecture

Volatility of hydrocarbon markets and its further challenges are inevitable. Drastic price shrinkage in global energy market in 2015 and 2020 have proved that still vast majority of economies in the world are easily vulnerable on spillover effect of price instability. In fact one of the main reasons is discrepancy in demand and supply interaction, either emanated from short-term national interests or market behavior. ECO region, is of course also are one of affected ones. In this regard, enhancing regional cooperation to find possible solutions in preventing the causes of price volatility, along with eliminating its adverse effects will be included on the regular agenda of ECO Energy Ministerial meetings.

Strengthening the role of the ECO Region in global energy architecture through undertaking *integrated, coordinated, and complementary common position* is of utmost importance. The strategy of ECO member states in advancing its energy policy towards existing and new partnerships in global landscape will be based on the values such as *shared interests, equality and coherence.* Upon joint decisions, ECO member states will coordinate their positions in global energy agenda complementing to their shared interests.

It is obvious that today *unnecessary competitions* expose threat to the stability of market and unravel the regional cooperation. To achieve resilience in overcoming such challenges ECO intends to put forward common policies supporting rationalization of supply and demand both in regional and global level. Eventually adjusting coordination of supply quota in the markets where two or more ECO Member States participate, will contribute to the stability of price and energy security. Besides, it will improve to speak with one voice in other multilateral fora, thus further strengthen the role of ECO region in global energy landscape.

CONCLUSIONS

1. Diversification of energy sources and energy connectivity are fundamental in the ECO region given the unique geostrategic position and landlocked nature of most ECO member states.

2. It is shown that coercive mechanisms may be required to transform the energy balance to meet the needs of ECO member states through cooperation at the regional level and respond to priorities at the global level.

3. Improving energy connectivity among ECO countries will be a key tool in creating energy corridors.

4. To achieve sustainability in overcoming unjustified competition among countries, ECO should develop common policies that support the rationalization of supply and demand at both the regional and global levels.

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INCREASING THE EFFICIENCY OF ESTIMATION OF FLOW DISTRIBUTION IN ELECTRIC GRID WITH RENEWABLE ENERGY SOURCES USING A SIMPLIFIED REACTIVE POWER EQUATION

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A linearized model of reactive power flow in electric networks is proposed. The use of this model allows to increase the results and efficiency of modeling reactive current distribution in distribution networks of power systems with integrated renewable energy sources. When applying the proposed mathematical model in the general model of the balance of flow distribution in electric networks, it is possible to simplify and reduce the time of research and calculation experiment when analyzing established regimes. Test studies of the proposed mathematical calculation model were carried out on IEEE standard schemes and the real scheme of the Azerbaijan power system, and the results of the analysis showed the effectiveness of its application for the operational analysis of the system state.

Key words: energy system, electric system, reactive power equations, flow distribution, methods of calculating steady-state modes, methods of linearization

ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ ОЦЕНИВАНИЯ ПОТОКОРАСПРЕДЕЛЕНИЯ В ЭЛЕКТРИЧЕСКИХ СЕТЯХ С ВОЗОБНОВЛЯЕМЫМИ ИСТОЧНИКАМИ ЭНЕРГИИ С ИСПОЛЬЗОВАНИЕМ УПРОЩЕННОГО УРАВНЕНИЯ РЕАКТИВНОЙ МОЩНОСТИ

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Предлагается линеаризованная модель потока реактивной мощности в электрических сетях. Использования этой этого модели позволяет повысить результаты и эффективности моделирования реактивного потокораспределение в распределительных электрических сетях энергосистем с интегрированными возобновляемыми источниками энергии. При применение предлагаемого математического модели в общей модели баланса потокораспределения в электрических сетях позволяет упростить и сократить время исследования и расчетного эксперимента при анализе установившегося режимов. Проведены тестовые исследования

предлагаемой математической расчетной модели на стандартных схемах IEEE и реальной схеме Азербайджанской энергосистемы и полученные результаты анализа показали эффективность ее применения для оперативного анализа состояния системы.

Ключевые слова: энергосистем, электрическая система, уравнения реактивная мощности, потокораспределения, методы расчета установившихся режимов, методы линеаризации

BƏRPAOLUNAN ENERJİ MƏNBƏLİ ELEKTRİK ŞƏBƏKƏLƏRİNDƏ SADƏLƏŞDİRİLMİŞ REAKTİV GÜC TƏNLİYİNİN TƏTBİQİ İLƏ GÜC AXINLARININ OPERATİV İDARƏOLUNMASI EFFEKTİVLİYİNİN ARTIRILMASI

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Elektrik şəbəkələrində reaktiv enerji axınının xəttiləşdirilmiş modeli təklif edilmişdir. Bu modelin istifadəsi inteqrasiya olunmuş bərpa olunan enerji mənbələri ilə enerji sistemlərinin elektrik paylayıcı şəbəkələrində reaktiv axının paylanmasının modelləşdirilməsinin nəticələrini və səmərəliliyini yaxşılaşdırmağa imkan verir. Təklif olunan riyazi modelin elektrik şəbəkələrində axınların paylanması balansının ümumi modelində tətbiqi dayanıqlı vəziyyətin təhlili zamanı tədqiqat və hesablama təcrübələrinin vaxtını sadələşdirməyə və azaltmağa imkan verir. Təklif olunan riyazi hesablama modelinin sınaq tədqiqatları standart IEEE diaqramları və Azərbaycan enerji sisteminin real diaqramı üzərində aparılıb və alınan təhlil nəticələri sistemin vəziyyətinin operativ təhlili üçün ondan istifadənin səmərəliliyini göstərib.

Açar sözlər: enerji sistemləri, elektrik sistemi, reaktiv güc tənliyi, axının paylanması, sabit vəziyyət şərtlərinin hesablanması üsulları, xəttiləşdirmə üsulları

INTRODUCTION

The analysis of steady-state modes is the basis for planning, operation and management of power systems (PS), the importance of which increases when the system operates in the conditions of the electric power market.

The calculation of the flow distribution is based on solving a system of nonlinear algebraic equations describing the steady-state mode. To solve these equations, various computational algorithms have been proposed and developed, with the help of which known methods for solving nonlinear algebraic equations in the literature are implemented [1-5]. These methods are iterative and the efficiency of their application significantly depends on the complexity of the system under study. In this regard, all subsequent developments to improve the algorithms based on the application of the above methods are reduced to an acceptable simplification of the models describing steady-state modes [6,7].

This article proposes an improved method for estimating the flow distribution in electrical networks of the power system, developed by linearizing the equations for reactive power. The proposed method has the ability to quickly calculate the voltage on the load buses and the injection of reactive power on the generator buses, which is necessary for the operational dispatch control of the flow distribution in electrical networks with distributed generation based on integrated renewable energy sources. Initially, the idea of linearizing the reactive power equations was proposed in [8] and [9-13]. Numerous studies on power distribution in electric networks confirm the need to develop effective mathematical model algorithms for performing flexible reports of power distribution for operational control of the regime [14-25].

In this paper, a mathematical formulation of the method of linearized representation of the reactive power equation is proposed to increase the efficiency of the estimation of flow distribution in electrical networks with renewable energy sources..

1. SIMPLIFIED FORMULATION OF THE MODEL FOR THE CALCULATION OF FLOW DISTRIBUTION ACCORDING TO REACTIVE POWER

An n-node typical EC scheme is considered, in which the balance of reactive power in the i-th node, in polar form and relative units:

$$q_i = u_i \sum_{k=1}^{n} u_k \ Y_{i,k} \sin\left(\theta_i - \theta_k - \varphi_{i,k}\right) \tag{1}$$

where $u_i, u_k -$ voltage in the nodes i and k.

In this equation, the number of unknowns depends on the type of node: if the knot *i* type *PQ*, then unknown voltages, or if a knot *i* is the type *PV*, it is unknown q_i. The phase angles of the voltages are the main parameters that can be pre-calculated by means of the power distribution of the direct current. It should be noted that the DC load flow conductivity matrix differs from the complete conductivity matrix of equation (1); In this case, the elements must take into account not only the longitudinal, but also the transverse conductivity of each element of the network.

Returning to equations (1) neglecting the longitudinal and transverse active conductivity and assuming B_{ik}, module of the reactive conductivity of the typical element of the conductivity matrix, we get:

$$q_i = u_i \sum_{k=1}^{n} u_k \ Y_{i,k} \sin\left(\theta_i - \theta_k - \varphi_{i,k}\right) = -u_i^2 B_{i,i} - u_i \sum_{\substack{k=1 \\ k \neq i}} u_k B_{i,k} \cos\left(\theta_i - \theta_k\right) \tag{2}$$

For everyone *g* generator unit Δv known, here for $i \in [1, g]$ we get:

$$q_i + \sum_{\substack{k=g+1 \\ i}}^{n} \Delta u_k B_{i,k} \cos(\theta_i - \theta_k) = -B_{i,i} - 2\Delta u_i B_{i,i} - \sum_{\substack{k=1 \\ k\neq i}}^{n} B_{i,k} \cos(\theta_i - \theta_k) - \Delta u_i \sum_{\substack{k=1 \\ k\neq i}}^{n} B_{i,k} \cos(\theta_i - \theta_k) - \\ - \sum_{\substack{k=1 \\ k\neq i}}^{g} \Delta u_k B_{i,k} \cos(\theta_i - \theta_k) \quad (3)$$

For everyone (*n-g*) load node, we assume for $i \in [g+1, n]$ we get:

$$2\Delta u_i B_{i,i} + \Delta u_i \sum_{\substack{k=1 \\ k\neq i}}^{n} B_{i,k} \cos(\theta_i - \theta_k) + \sum_{\substack{k=g+1 \\ k\neq i}}^{g} \Delta u_k B_{i,k} \cos(\theta_i - \theta_k) = \\ -q_i^0 - B_{i,i} - \sum_{\substack{k=1 \\ k\neq i}}^{n} B_{i,k} \cos(\theta_i - \theta_k) - \sum_{k=1}^{g} \Delta u_k B_{i,k} \cos(\theta_i - \theta_k) \quad (4)$$

Here q_i^0 specified reactive power (in p.u.) consumed by the load at the *i-th* node. By rearranging the n equations in such a way that the first "*g*" were important for generator nodes, and the remaining (n-g) were important for load nodes, then the system can be written as:

$$\begin{vmatrix} I & R^{gc} \\ O & R^{cc} \end{vmatrix} \begin{vmatrix} q^g \\ \Delta u^c \end{vmatrix} = \begin{vmatrix} q^{\Sigma g} \\ q^{\Delta c} \end{vmatrix} \quad (5)$$

here:

$$R_{h,j}^{gc} = B_{i,k} \cdot \cos(\theta_i - \theta_k) \quad (6)$$

с $i = h, \quad k = j + g, \; h \in [1, g], \quad j \in [1, n-g],$

$$\mathrm{R}_{\mathrm{h,h}}^{\mathrm{c,c}} = 2B_{i,i} + \sum_{\substack{k=1 \\ k\neq i}}^{n} B_{i,k} \cos(\theta_i - \theta_k), \quad \text{с} \quad i = h + g, \; h \in [1, n-g], \quad (7)$$

$$\mathrm{R}_{\mathrm{h,j}}^{\mathrm{c,c}} = B_{i,k} \cos(\theta_i - \theta_j) \quad (8)$$

с $h \neq j, \; i = h + g,$ и $k = j + g, \quad h, \; j \in [1, n-g],$

$$q_i^{\Sigma g} = -B_{i,i} - 2\Delta u_i B_{i,i} - \sum_{\substack{k=1 \\ k\neq i}}^{g} B_{i,k} \cos(\theta_i - \theta_k) - \Delta u_i \sum_{\substack{k=1 \\ k\neq i}}^{n} B_{i,k} \cos(\theta_i - \theta_k) - \sum_{\substack{k=1 \\ k\neq i}}^{g} \Delta u_k B_{i,k} \cos(\theta_i - \theta_k) \quad (9)$$

с $i \in [1, g],$

$$g_i^{\Delta c} = -q_i^0 - B_{i,i} - \sum_{\substack{k=1 \\ k\neq i}}^{n} B_{i,k} \cos(\theta_i - \theta_k) - \sum_{k=1}^{g} \Delta u_k B_{i,k} \cos(\theta_i - \theta_k) \; \text{с} \quad i \in [g+1, n] \quad (10)$$

Considering equation (6) as a second-order product, we obtain an unknown vector

$$R^{cc}\Delta u^{c} = q \tag{11}$$

which is a linear system of (n-g) equations with (n-g) unknown variables Δu^{c}

$$\Delta u^{c} = R^{cc-1}q^{\Delta c} \tag{12}$$

The previous equation allows us to calculate the stresses at the load nodes. It is important to note that the matrix transport order R^{cc} equal, $l\,x\,l$ here l number of load nodes.

Considering equation (5) once again as the product of the first load and the unknown vector, we finally obtain an expression for the reactive power produced by the generators:

$$q^{g} = q^{\Sigma g} - R^{gc}\Delta u^{c} \tag{13}$$

here Δv^{c} is known from equation (11).

3. RESULTS OF COMPUTATIONAL AND EXPERIMENTAL MODELING

Based on the proposed method, calculation experiments were performed for the standard IEEERTS-96 scheme, the scheme and mode data of which are given in detail in [9,10]. This scheme has 59 generator units, 120 branches and 73 nodes. The peak load is 400 MW. The topology of one of the parts with 24 nodes is shown in Fig. 1. As can be seen from the figure, WT1 and WT2 wind farms with final capacities of 10 MW and 230 MW are connected to nodes 1 and 14, respectively.

With the help of the ETAP software complex, a report of the normal steady state was made, and the distribution of active and reactive power flows along the electric transmission lines was determined.

Table 1 shows the results of the flow distribution calculations in the considered network with renewable energy sources. The known nodal data assumed as inputs are: busbar type, injections P and U for nodes (*PU*), injections of active and reactive power (for PQ nodes). The permissible generation of reactive power for each generator and the possible min and max voltage values are also specifically specified.

Voltage and reactive power errors are always no more than 1.5% and 10%, respectively. The root-mean-square error for voltage is 0.5% and 4.6% for reactive power.

Including the time required to calculate and analyze the flow distribution of reactive power in electrical networks, the execution speed of the algorithm relative to known methods was 6-7 times faster.

As can be seen from the data in Table 1 and the analysis of the report results of the mode, the loads on the branches of the considered circuit do not exceed the allowable norms for them, and the voltages at the nodes of the circuit are mostly within the allowable limits (Figure 2). The obtained results can be used in the final balance sheets of the presented linearized mathematical model for the reporting of reactive power flows, and in this case, the final results can be achieved more quickly, it is convenient to apply the mode for operative management.

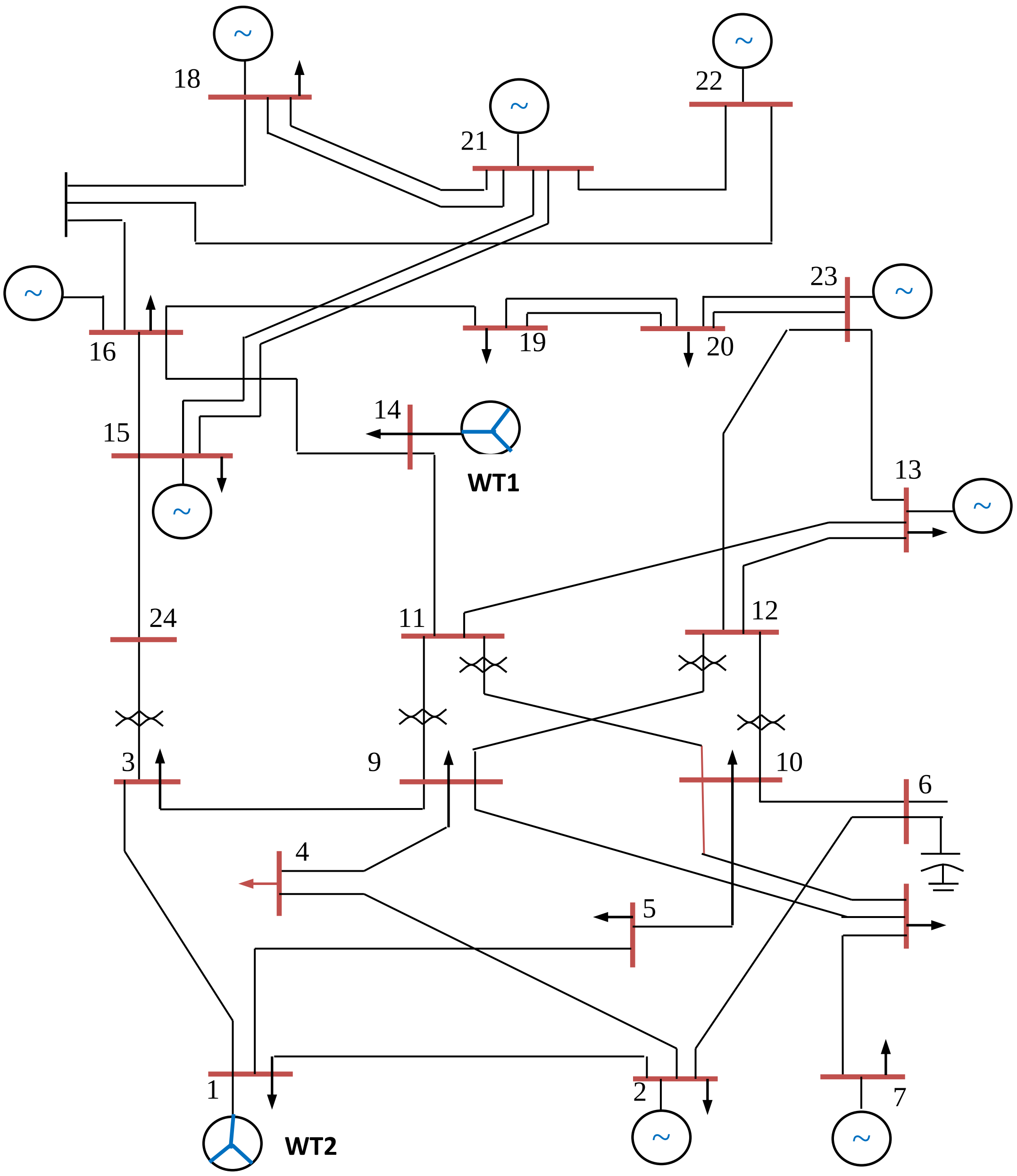

Fig. 1. IEEE IEEERTS-96 standard electrical network circuit

Table 1. Results of the calculation of flow distribution in the IEEE standard network

Node name	U_{nom} kV	U_{cal} p.u	$\cos\varphi$	Power	
				P, MW	Q, MWAr
13-5	110	0,942	0,422	7,661	16,468
3-12	35	0,999	0,997	11,395	0,907
3-15	35	0,992	0,975	12,3	0,799
3-12	35	0,992	0,975	24,85	5,612
3-14	35	0,992	0,813	9,274	2,228
3-17	35	0,993	0,574	4,882	6,968
3-10	35	0,977	1,0	8,657	0,036

3-16	35	0,977	0,59	4,873	6,827
3-15	35	0,976	0,971	9,248	2,291
3-18	35	0,968	0,763	4,425	3,755
13-1	110	1,013	1,0	220,0	5,630
13-6	110	1,000	0,992	82,96	10,36

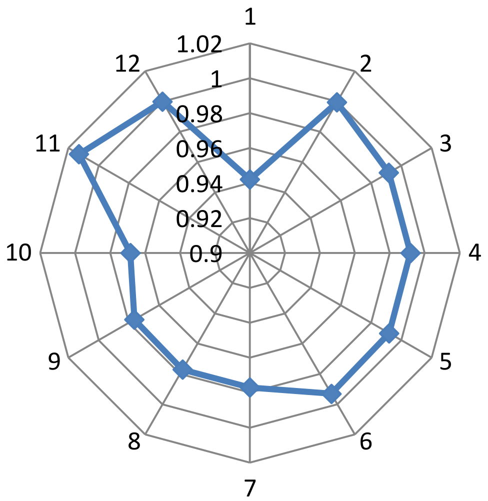

Fig. 2. Voltage profile for standard IEEERTS -96 circuit

Fig. 2 shows the profile of voltages on 12 characteristic nodes of the circuit. As can be seen from the stress profile, the relative value of stress in only one beam (node 13-5) is 0.942, in other words, it is relatively low. The voltages on other tires are in acceptable ranges. Based on the results of the report, by implementing various regime measures, it is possible to reorganize the distribution of powers and obtain the complete relegation of the regime.

At the next stage, a corresponding power distribution report was made for the real electricity network with distributed generation (Sabail network region) based on wind and solar energy sources. The considered network is included in the 110/35/6/0.4 kV voltage system of "Azerishiq" OJSC, it was implemented according to the radial-main type scheme (Figure 3). 55 distribution lines serve the network within the balance boundaries of Sabail Network district. 44 of these lines are under load. The other 11 lines were kept in emergency mode. Since Sabail region is strategically a network with a large number of category 1 consumers, it is considered inadmissible to cut off electricity. The transmission substations feeding the network are 220/110/10 kV Mushfiq substation (feeding Bayil and Badamdar substations) and 110/35/6 kV Puta substation (feeding Shikh substation) owned by Azerenergy OJSC. The total consumption capacity of Sabail region is 99.5 MVA, and its active capacity is 97.5 MW. This shows that $\cos\varphi$ is 0.979. Despite the fact that the network district is fed from 2 different sources, only 12.2 MVA of the consumption power falls on the Shikh substation. This means approximately 12.2% of the total consumption. The remaining 87.8% of the consumption capacity falls on the Badamdar and Bayil substations, which are fed from the Mushfiq substation. This means that as a result of the opening of the Mushfiq substation, 87.8 percent of consumers of Sabail region will have a break in the use of electricity. To prevent this, if we provide these parts of the network with 2 renewable energy sources, this will prevent the generation of electricity in electricity consumers, and also expand the part that can be increased, which may fall on the Shikh substation in case of an emergency. A 2-unit system with a 15 MVA

wind turbine feeds the Bayil substation, and a 2-unit solar power plant with an integrated photovoltaic system of 5 MVA each feeds the Shikh substation.

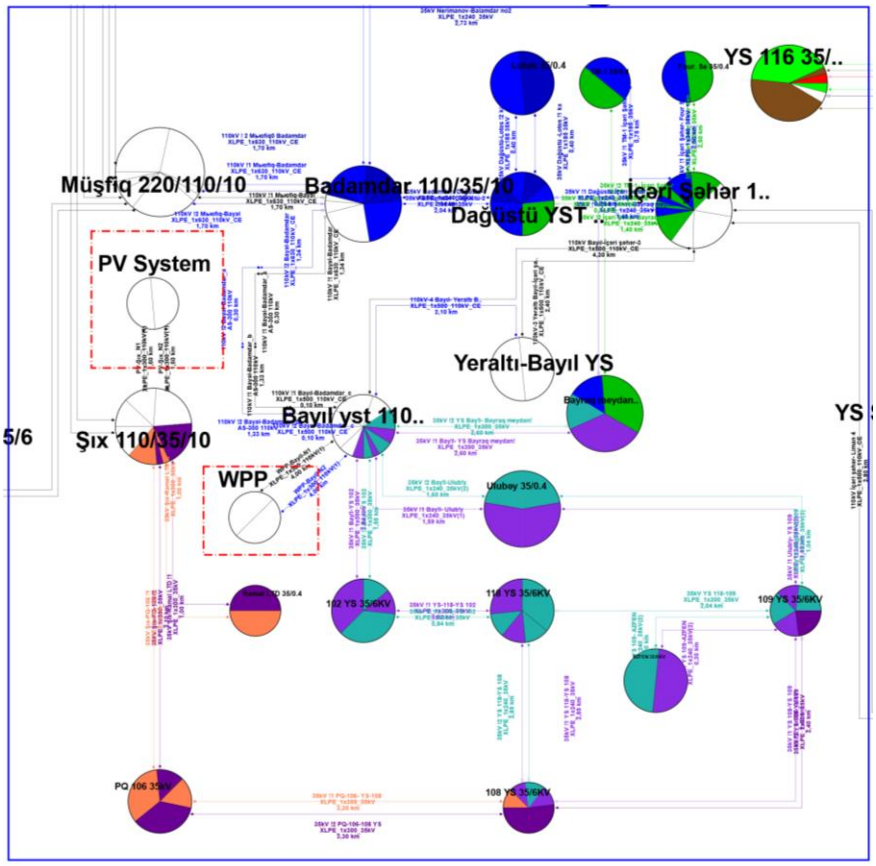

Fig. 3. Puta-DOZ-Shikh branching of Sabail network district connection scheme for voltage steps

Table 2. Reporting results of the established regime for the Sabail network district

Node name	U_{nom} kV	U_{cal} p.u	$tg\varphi$	Power	
				P, MW	Q, MWAr
1	110	0,999	0,252	35,8	9,03
2	110	0,999	0,243	25,26	6,14
3	110	1,000	0,143	28,26	4,03
4	35	0,995	0,221	5,22	1,15
5	110	1,000	0,405	1,02	0,41
6	35	0,995	0,260	1,13	0,29
7	35	1,000	0,204	0,015	0,003
8	35	1,000	0,204	0,137	0,028
9	35	0,994	0,225	0,52	0,116
10	110	1,000	0,142	28,26	4,01
11	110	1,013	1,141	28,27	3,99
12	35	0,981	0,228	0,70	0,159

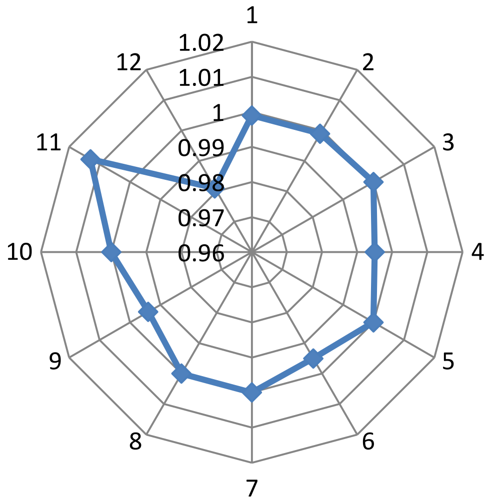

Fig. 4. Profile of tension on characteristic nodes of the Sabayel network district

The report was performed using the DIgSILENT PowerFactory software package. As can be seen from the diagram, a 15 MW wind farm and a 5 MW solar plant are connected to one node of the electric network. The rest of the power comes from the system and into the grid. The results of the fixed mode report are given in Table 2 and Fig. 4.

The analysis of the report results carried out on the real network confirmed the results obtained according to the IEEERTS-96 scheme. In other words, the integrity of the results of the report based on the obtained mathematical model provides a basis for its use in regime management.

CONCLUSIONS

The non-linear complex structure of the existing mathematical models creates certain difficulties in order to ensure the calculation and analysis of normal steady-state modes and operational-dispatching management of power flows in distributed generation power networks based on renewable energy sources. For this purpose, the method of linearization of flow distribution by reactive power in electric networks with distributed generation based on renewable energy sources is proposed. The method is capable of operationally calculating voltages on load buses, as well as injection of reactive power on electricity generation buses, and can be successfully used to assess the mode reliability of power systems and optimize flow distribution in an electric network with distributed generation.

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BIOGRAPHY

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"Small and Medium Business Development Agency of the Republic of Azerbaijan"

STUDY OF PHYSICAL AND TECHNICAL PARAMETERS OF GEOTHERMAL WATERS OF MASALLI REGION OF AZERBAIJAN.

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Abstract

The only truly environmentally friendly, waste-free and, most importantly, inexhaustible resource is underground heat, on which geothermal energy is based. For this purpose, the study of the physical and technical parameters of geothermal waters in the Masalli district, depending on the seasons of the year, is given in the article. The article presents experimental data on the density of geothermal water at a certain pressure and temperature from the Masalli region of Azerbaijan using a high-precision experimental device - a vibrating tube density measuring device.

Keywords: geothermal waters, experimental investigations, density, physical and technical properties.

Аннотация.

Единственным по-настоящему экологически чистым, безотходным и, главное, неисчерпаемым ресурсом является подземное тепло, на котором основана геотермальная энергетика. С этой целью в статье приводится исследование физико-технических параметров геотермальных вод Масаллинского района в зависимости от сезонов года. В статье представлены экспериментальные данные по плотности геотермальной воды при определенном давлении и температуре из Масаллинского района Азербайджана с использованием высокоточного экспериментального прибора - вибрационного трубчатого плотномера.

Ключевые слова: геотермальные воды, экспериментальные исследования, плотность, физико-технические свойства.

Introduction. This publication was prepared with the financial support of the Small and Medium Business Development Agency of the Republic of Azerbaijan. The agency is not responsible for the content of the publication."

This paper investigates the thermophysical properties of geothermal water from springs of Masalli region of Azerbaijan. Geothermal energy is a part of alternative energy and is widely used in the world for various purposes. In recent years, as traditional energy sources are becoming more

expensive and may be insufficient in the future, technologies utilizing thermal waters have been actively developed. In order to apply geothermal water in various energy installations, knowledge of its characteristics such as pressure, density and temperature is necessary. Geothermal water studies have been conducted in Azerbaijan for a long time [1-4], but most of them are concentrated on geological analysis and composition of chemical elements. The thermophysical aspect is practically not considered. This material presents experimental results of studying thermophysical properties of geothermal water of Masalli region in Azerbaijan. Geothermal sources of Azerbaijan are low-temperature sources. Despite this, the utilization of geothermal energy in Azerbaijan is very promising. Estimates show that by cooling thermal waters by 20-40° C, a total of 700 MW of energy can be obtained from all known geothermal sources in Azerbaijan.

Methods. Experimental studies of the pρT dependence of fluids can be carried out by various methods. To measure the density of geothermal springs in the Masalli region of Azerbaijan at high pressures and temperatures (pρT data), a high-precision experimental setup implementing the vibration tube densimeter method was used [5]. This method in modern experimental thermophysics is characterized by high accuracy of measurements, simplicity, insignificant time and economic costs, as well as the possibility of automation of the measurement process. The principle of operation of the experimental setup is based on the dependence of the oscillation period of the tube is based on the dependence of the vibration period of a tube filled with liquid on the density of this liquid. The behavior of the vibrating tube can be described by a mathematical model of the vibrations of a solid. behavior of the vibrating tube can be described by a mathematical model of solid body oscillations [6]. When the vibrating tube makes a harmonic oscillation, the value of the restoring force F is proportional to the displacement x according to Hooke's law:

$$F = -kx, \tag{1}$$

where F is the rod tension or restoring force, x is the distance between the current and equilibrium position of the vibrating tube, k is the elasticity coefficient.

$$F = ma = -kx, \tag{2}$$

where ***m*** is the mass of the tube.
Given that the acceleration is the second derivative of the coordinate in time, we obtain an ordinary differential equation:

$$x + w_0^2 \cdot x = 0 \tag{3}$$

here $\frac{k}{m} = w_0^2$ .It is assumed that the oscillations are free and the damping in the system is completely neutralized by the external applied torque. Equation (3) describes the behavior of harmonic oscillations and its solution has the following form:

$$x = A\cos\,(w_0 t + \varphi_0) \tag{4}$$

where A- is the amplitude of oscillations, ω_0 - is the amplitude of oscillations, ***t***- is time, φ_0 - is the initial phase.
For the full phase of change, the following provisions apply:

$$w_0(t+\tau)+\varphi_o = w_0 t + \varphi_0 + 2\pi \quad (5)$$

where τ - is the period of vibration of the vibrating tube.
Then we get

$$\tau = 2\pi\sqrt{\frac{m}{k}})3 \quad (6)$$

The mass of the vibrating tube ***m*** is equal to the sum of the masses of the empty tube $\boldsymbol{m_0}$ and the mass ρV(T,p) of the liquid filling the tube. Besides, in general case the tube volume V(T.p) also depends on pressure and temperature:

$$\tau = 2\pi\sqrt{\frac{m_0+\rho\cdot V(T.p)}{k(T.p)}} \quad (7)$$

The following relationship is finally obtained, relating the density of the fluid to the frequency of oscillation:

$$\rho = \mathrm{A(T.p)} - \mathrm{B(T.p)}\tau^2 \quad (8)$$

where $A(T.p) = -\frac{m_0}{V(T.p)}.\ B(T.p) = \frac{k\ (T.p)}{4\pi^2 V(T.p)}$

The coefficients A1(T,p) and B1(T,p) contain values depending only on the material and geometry of the tube and can be determined by analyzing the dependence of the oscillation period on the density for at least two liquids for which (pρT) data are known with high accuracy.
The main element of the experimental setup of the densimeter with an inversion tube DMAHPM by Anton-Paar is a measuring cell, inside of which there is a vibrating tube Hastelloy C-276, made of nickel-based stainless steel alloys with high corrosion resistance. The composition of the Hastelloy alloys, as a rule, includes mainly nickel (Ni up to 57%), chromium (Cr 14.5-16.5%), molybdenum (Mo 15-17%), iron (Fe 4-7%), tungsten (W 3- 4.5%). Cobalt, copper, manganese, titanium, zirconium, aluminum, tungsten, vanadium and niobium are used as alloying additives. The main advantage of these alloys is efficient operation at high temperatures and pressures, as well as in contact with aggressive media, while conventional or cheaper alloys do not adequately meet the technological requirements. The vibration tube has the following geometrical dimensions: the length of each elbow is about 15 cm, the radius of curvature between the elbows of the tube is about 1 cm, the outer diameter is 0.635 cm and the inner diameter is 0.28 cm. At the same time, the volume of the substance filling the vibration tube, is about 2 cm^3.The measuring cell is connected to a computer using an interferometer and the mPDS2000V3 temperature and pressure control system. The measuring cell is designed to measure temperatures in the range T=263.15-473.15 K and pressures p=0.1-140 MPa. The electron-magnetic system of the measuring cell creates and measures the period of tube oscillations and transmits their value to the computer during the whole time of the experiment. The temperature in the measuring cell, where the U-tube is located, is maintained using an external thermostat F32-ME (Julabo, Germany) with an error of 0.01 K. The calibration of the unit was carried out by measuring the oscillation period of water, aqueous solutions of NaCl, methanol, ethanol and toluene at temperatures T=(263.15-468.15) K and pressures up to p=140 MPa.

Results. Unlike ordinary water, thermal water contains more salt and gas in its composition. It contains different types of gases and a certain amount of dissolved salts. geothermal water of Masalli district from springs in the village of Geribler. contains hydrogen sulfide, sodium-chloro-calcium, magnesium hydrogen carbonate and 30 milligrams of iodine per liter. The solution comes out from very deep in the earth at temperatures above 45-50 ° Celsius. The geographical coordinates of the thermal water and its temperature at the moment it leaves the spring are given in the table.

Table 1 - Geographic coordinates and temperatures of thermal waters at the moment of release from the source

Source name	Geographical coordinates	Temperature at the time of release
Geribler	N 38.99750 E 48.59639	45-50°C

Experimental studies of pρT dependence of liquids can be carried out by different methods. To measure geothermal water of Masalli region from springs in the village of Geribler at high pressures and temperatures (pρT data), a high-precision experimental setup implementing the vibrating tube densimeter method was used [6]. The experiment is conducted in static mode, where the sample is introduced into a vibrating tube with a pressure intensifier and remains motionless during the measurement at the desired pressure. The density measurement error under these conditions was $\Delta\rho/\rho = \pm(0.01 - 0.03)$ %. Measurements of (p,ρ,T) dependences were carried out by isotherms from the minimum possible pressure for a given temperature, and further increasing it in steps of about 10 MPa. The studies were carried out at temperatures in the range T=(273.15 to 413.15) K and pressures up to p=100 MPa. At atmospheric pressure, the obtained density values were compared with the density values measured on the DSA 5000M.

The data obtained by different methods agree well with each other within $\Delta\rho/\rho = \pm 0.02$ %.The obtained results of density of Masalli region from springs in the village of Geribler are shown in Table 1.

Table 1 - Experimental values of density ρ, temperature T of Masalli region from springs in the village of Geribler.

P/MPa	**ρ/kq·m³**	**T/K**	**P/MPa**	**ρ/kq·m³**	**T/K**
0.101	1011.30	273.15	0.101	971.10	372.91
1.001	1010.73	273.15	1.770	971.91	372.88
5.002	1013.70	273.15	5.720	974.02	372.91
10.010	1015.02	273.15	10.301	976.04	372.91
20.056	1020.71	273.15	20.110	980.38	372.91
30.086	1022.21	273.15	30.007	984.06	372.91
39.950	1027.70	273.15	40.080	988.17	372.92
50.010	1033.01	273.15	50.047	992.10	372.91
60.045	1037.20	273.15	60.400	996.10	372.92
70.030	1043.33	273.15	70.054	999.84	372.91
80.056	1045.30	273.15	80.054	1003.42	372.91
91.956	1048.20	273.15	90.106	1007.02	372.92
100.006	1053.01	273.15	100.160	1010.60	372.91

0.101	1012.50	278.01	0.101	956.16	393.15
0.941	1013.04	278.00	1.043	957.15	393.15
4.622	1016.53	278.00	5.014	959.26	393.15
10.453	1018.20	278.00	10.060	961.20	393.14
20.660	1020.05	278.01	20.104	965.80	393.15
30.054	1025.21	278.00	30.144	970.25	393.16
40.201	1030.20	278.01	40.020	975.60	393.16
50.093	1033.41	278.00	50.104	979.82	393.15
60.056	1038.03	278.01	60.084	983.41	393.13
69.983	1043.02	278.00	69.784	986.73	393.15
79.925	1033.40	332.94	80.020	991.01	393.14
89.993	1035.01	332.92	90.012	994.12	393.16
99.997	1038.39	332.90	100.135	997.63	393.15
0.101	984.20	353.15	0.412	940.12	413.17
1.204	984.44	353.15	1.608	941.02	413.13
5.006	985.94	353.15	5.426	943.03	413.17
10.024	987.94	353.14	10.020	945.13	413.18
20.105	992.30	353.15	20.150	950.24	413.18
30.106	995.92	353.16	30.206	955.13	413.19
40.006	1000.30	353.13	40.214	959.78	413.19
50.125	1004.10	353.15	50.179	964.13	413.18
60.050	1008.06	353.14	60.093	968.39	413.19
70.012	1012.05	353.15	70.006	972.59	413.18
80.010	1014.94	353.16	80.071	976.60	413.18
90.050	1019.04	353.16	90.993	980.40	413.18
100.023	1021.90	353.15	100.086	987.13	413.19

The measured densities as a function of pressure and temperature are fitted from the equation of state:

$$p(\rho,T)MPa = A(T)\cdot\left(\rho/g\cdot cm^{-3}\right)^2 + B(T)\cdot\left(\rho/g\cdot cm^{-3}\right)^8 + C(T)\cdot\left(\rho/g\cdot cm^{-3}\right)^{12} \quad (9)$$

where: coefficients A (T), B (T) and C (T) are functions of temperature.

$$A(T) = \sum_{i=1}^{4} a_i T^i,\quad B(T) = \sum_{i=0}^{3} b_i T^i,\ C(T) = \sum_{i=0}^{3} c_i T^i \quad (10)$$

here the coefficients A(T), B(T) and C(T) in Eq.(9) are functions of temperature. The obtained coefficients ai, bi and ci in equation (10) are presented in Table 2. Equations (9) and (10) describe well the experimental data of the density of Masalli region of Azerbaijan.

Table 2 - Values of coefficients ai, bi and ci in Equation 10.

ai	**bi**	**ci**
a_1 = -1.53616248 a_2 = -0.791761511·10^{-2} a_3 = 0.477877266323·10^{-4}	b_0 = 3158.56612362353 b_1 = -17. 43434536137	c_0 = -1581.7451488 c_1 = 7.8529161511843 c_2 = -0.450414887·10^{-2}

a_4 = -0.4151512736153145·10^{-7}	b_2 = 0.0467688357343136 b_3 = -0.148334325276·10^{-4}	c_3 = -0.251061487021·10^{-4}

The errors are calculated using the following equations

$$\mathrm{PD},\% = 100\left(\frac{\rho_{\mathrm{exp}} - \rho_{\mathrm{cal}}}{\rho_{\mathrm{exp}}}\right) \tag{11}$$

$$\mathrm{APD},\% = \frac{100}{\mathrm{N}}\sum\left|\frac{\mathrm{P_{EXP}} - \mathrm{P_{CAL}}}{\mathrm{P_{EXP}}}\right| \tag{12}$$

where ρ_{exp} is the measured density, ρ_{cal} is the calculated density from equation (11), and N is the number of points to be compared.

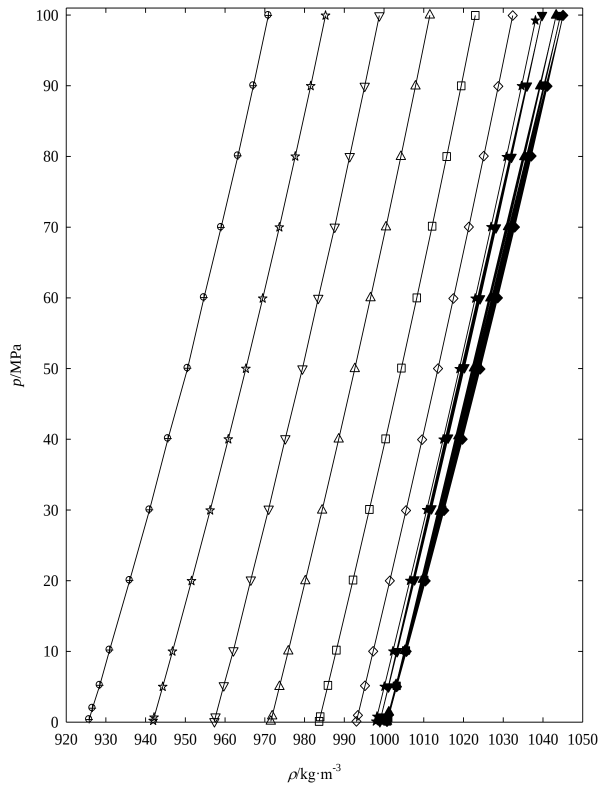

Figure 1: Density dependence of geothermal water of Masalli region of Azerbaijan on pressure at different temperatures:: ◆, 274.15 K; ■, 278.12 K; ▲, 283.21 K; ▼, 293.18 K; ★, 298.15 K; ◇, 313.15 K; □, 333.15 K; △, 353.15 K; ▽, 373.16 K; ☆, 393.15 K; ⊕, 413.15 K.

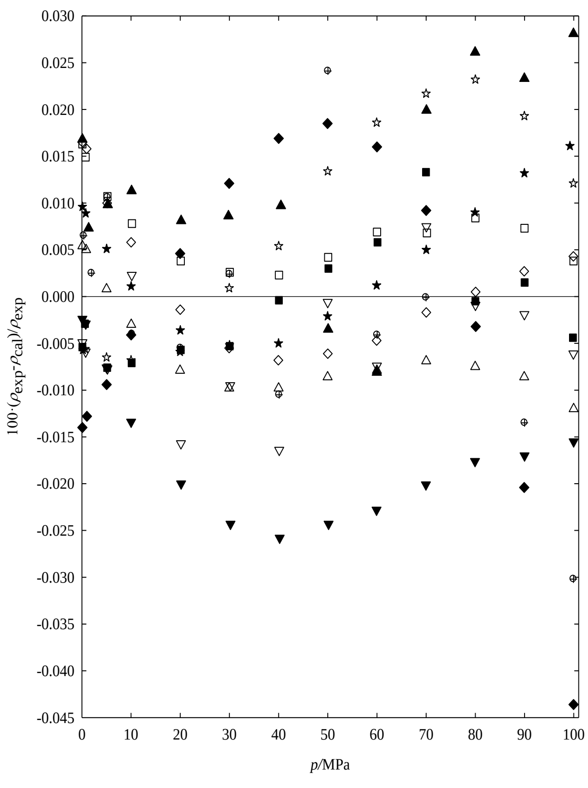

Figure 2: Dependence of the pressure p on the pressure p of the difference of the experimentally measured density of the "Geribler" water located in the Masalli region of Azerbaijan from the density ρ_{exp} calculated with the help of the equation of state:◆, 274.15 K; ■, 278.12 K; ▲, 283.21 K; ▼, 293.18 K; ★, 298.15 K; ◇, 313.15 K; □, 333.15 K; △, 353.15 K; ▽, 373.16 K; ☆, 393.15 K; ⊕, 413.15 K.

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ALTERNATIVE COOLANTS AND USE IN EXISTING COOLING SYSTEMS

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Abstract: The article mainly some characteristics of cooling systems and cooling agents used in them were discussed, and the possibilities of impact on the environment were investigated. Later, they were classified according to their environmental impact and the ways of their elimination were investigated. The issue of cooling agents destroying the ozone layer and causing global warming was highlighted and the importance of new alternative agents was emphasized. Refrigerant mixtures (azeotropic and non-azeotropic) that are prohibited for use every day are reported. The article also proposed new alternative agents and mixtures instead of cooling agents used in existing systems based on some experimental and literature studies.
Keywords: Refrigerant agents; cooling systems; ozone layer; Global Warming; azeotropic mixtures; alternative agents.

Key words: Refrigerants; cooling systems; ozone layer; global warming; azeotropic mixtures; alternative agents.

ALTERNATİV SOYUDUCU AGENTLƏR VƏ MÖVCUD SOYUTMA SİSTEMLƏRİNDƏ İSTİFADƏSİ

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Xülasə: Məqalədə əsasən soyutma sistemləri və onlarda istifadə olunan soyuducu agentlərin başlıca olaraq bəzi xüsusiyyətlərindən danışılmış və ətraf mühitə təsir imkanları araşdırılmışdır. Daha sonra onların ekologiyaya təsir imkanlarına görə təsnifatına geniş yer verilmiş və onların aradan qaldırılma yolları araşdırılmışdır. Soyuducu agentlərin istərsə Ozon təbəqəsinin dağıtmasına, istərsədə Qlobal istiləşməyə səbəb olmaları məsələsi önə çıxarılmış və yeni alternativ agentlərdən istifadə olunmanın vacibliyi üzərində dayanılmışdır. İstifadəsi hər keçən gün qadağan edilən azeotrop və azeotrop olmayan qarışıqlar haqqında məlumat verilmişdir. Məqalədə həmçinin bir qisim təcrübi və ədəbiyyat araşdırmalarına əsasən mövcud sistemlərdə istifadə olunan soyuducu agentlərin yerinə yeni alternativ agent və qarışıqlardan istifadə edil-məsinin vacibliyidən bəhs edilmişdir.

Açar sözlər: Soyuducu agentlər; soyutma sistemləri; ozon təbəqəsi; Qlobal İstiləşmə; azeotrop qarışıqlar; alternativ agentlər.

АЛЬТЕРНАТИВНЫЕ ХЛАДАГЕНТЫ И ИСПОЛЬЗОВАНИЕ В СУЩЕСТВУЮЩИХ СИСТЕМАХ ОХЛАЖДЕНИЯ

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Аннотация: В статье преимущественно обсуждались некоторые характеристики систем охлаждения и используемых в них хладагентов, исследовались возможности воздействия на окружающую среду. В дальнейшем они были классифицированы по степени воздействия на окружающую среду и исследованы пути их устранения. Был освещен вопрос о том, вызывают ли охлаждающие агенты разрушение озонового слоя или глобальное потепление и подчеркнута важность использования новых альтернативных агентов. Сообщается об азеотропных и неазеотропных смесях, применение которых запрещено ежедневно. В статье также упоминается важность использования новых альтернативных агентов и смесей вместо охлаждающих агентов, используемых в существующих системах, на основе некоторых экспериментальных и литературных исследований.

Ключевые слова: Хладагенты; системы охлаждения; озоновый слой; Глобальное Потепление; азеотропные смеси; альтернативные агенты.

Introduction.

Almost all refrigerants used in cooling systems have volatile properties. This means that the refrigerant used in the cooling system can only be used once in that system. Thus, in case of any repair or leakage, the working agent in the system is thrown into the environment and mixes with the atmosphere. Almost all refrigerants used in the early days have one or more of the properties of flammability, toxicity and corrosion. Freons are the basis of cooling agents used in cooling systems. Previously, these gases, which were considered harmless and very promising, later revealed negative effects on ecology [1]

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1. Purpose of work

The purpose of the research work is to investigate some characteristics of cooling systems and the cooling agents used in them and the possibilities of their impact on the environment, the possibilities of replacing them with new alternative agents due to the fact that they destroy the ozone layer and cause global warming.

2. Research methodology

In 1974, scientists Molina and Rowland conducted a study on the potential of refrigerants to damage the ozone layer, claiming that CFC-containing refrigerants would lead to a depletion of the ozone layer of about 7% over 60 years. As a result of this research, in 1978, the US government

banned the use of CFCs in aerosol sprays. After this date, scientists began to observe the depletion of the ozone layer. In 1985, Molina and Rowland's theory was finally confirmed as a result of research conducted by NASA. Based on these studies, scientists from different countries have confirmed that there is a hole in the ozone layer on the Antarctic continent, and they have accurately proven that the ozone layer has been holed by taking measurements to detect the effects of the sun's harmful rays from the glaciers.

Due to the fact that the rapid destruction of the ozone layer was confirmed, in July 1987 in Montreal, Canada, a protocol was signed between 24 countries and the countries of the European Economic Union to control the use of substances that deplete the ozone layer, and the time when CFCs were separately accepted. it was decided to reduce or even completely ban its use. In January 1990, new decisions were taken in London with the participation of 54 countries in order to strengthen the Montreal Protocol in 1987 for the assessment and investigation of ozone depletion. Thus, in these decisions, the act of support for the decisions taken in the Montreal protocol is indicated [2,3].

It has been emphasized that CFC compounds are at the root of the problem of ozone depletion and have a property that makes it important to use it as a refrigerant. Since CFCs are very difficult to break down, they can remain in the atmosphere for a long time before entering the stratosphere. When they cross the stratosphere, they get energy by being exposed to strong ultraviolet radiation. This energy they receive breaks the CFC molecules and the Cl atom is released. The free Cl atom splits the ozone molecules into O2 molecules as shown in the figure 4.

As can be seen from Figure 1, the Cl atom acts as a continuous catalyst, causing this decomposition to continue indefinitely. It is estimated that one Cl atom breaks 100,000 ozone molecules.

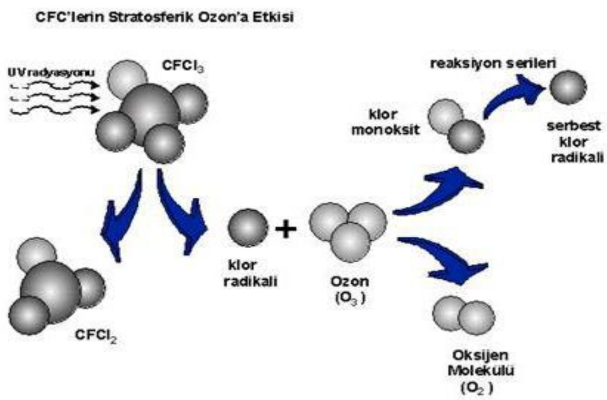

Figure 1. Mechanism of ozone layer depletion

Refrigerants are mainly classified under two headings, pure and mixed:

a). Pure refrigerants; they are inorganic and organic.

- inorganic refrigerants: Examples of this group include carbon dioxide, ammonia and sulfur dioxide.

- organic refrigerants: Belongs to this group;

1. Bromofluorocarbons (Hallons). Halones are the compounds that are most responsible for the destruction of ozone and are formed from the combination of bromine and chlorine.

2. Chlorofluorocarbons (CFCs). Chlorine, fluorine and carbon are refrigerants. After hallons, they are the second most damaging compounds to ozone. However, they are non-toxic and non-flammable.

3. Hydrochlorofluorocarbons (HCFCs). They are not as dangerous as others in terms of ozone depletion, but they have a very high carbon impact potential.

4. Hydrofluorocarbons (HFCs). This group of cooling agents has the property of not damaging the ozone layer.

b). Mixed refrigerants. Refrigerants in this group are substances formed by mixing pure refrigerants with a certain percentage. They can be divided into two parts.

• azeotropic refrigerant mixtures: The boiling and condensation point behavior of such mixtures is similar to that of pure refrigerants. They can evaporate and condense at constant pressure and temperature.

• non-azeotropic refrigerant mixtures: In such mixtures of two or more substances, the combinations of saturated liquid and saturated vapor phases are thermodynamically different from each other. Therefore, evaporation and condensation processes that take place under constant pressure cannot be carried out at constant temperature. While evaporation and condensation processes occur under constant temperature in systems using azeotropic mixture, these processes occur under variable temperature in non-azeotropic mixtures. Therefore, azeotropic mixtures are preferred due to these properties.

3. Discussion of results

As we have discussed, we are living in a developing century and at a time when we demand comfortable living standards, it is impossible for us to take a step back due to the use of technology. It is an axiom that we cannot avoid the use of cooling systems, just as we are forced to use fossil fuels to sustain our lives. Humanity and living conditions are in this situation, there are two ways to go:

- The first of these is to use the existing cooling systems all over the world for as long as possible and release the gases used there later.

- The second option is to invent cooling agents with new special features according to the existing cooling systems and technologies and to maintain their use.

The most important first parameter that indicates the characteristics of the refrigerants to be used in a cooling system is the type of compressor, and the second parameter is the type of evaporator. For this reason, the refrigerant gas proposed instead of an unpromising agent should work without problems in the existing compressor and maintain sufficient cooling. Apart from that, for the proposed alternative refrigerant gases, a compressor can be designed according to their properties, in which case the financial costs will increase more and it will be necessary to design a new cooling system. For this reason, during the appointment of alternative cooling agents, agents suitable for existing systems should be investigated [5,6].

In the article, instead of cooling agents that are compatible with existing systems and currently used, cooling agents that do not harm nature or reduce their damage in serious maintenance are investigated. For this purpose, some alternative gas mixtures were experimentally studied in the heat pump system, and some were found as a result of literature research and are listed in Tables 1, 2 and 3.

It should be noted that, as discussed in the article, refrigerants can be ranked by ozone depletion potential (ODP), global warming impact, flammability, toxicity, evaporation, and critical

heat values. Also, the criteria mentioned here are taken as a base and included in the ranking along with the existing cooling agents.

Table 1.Alternative refrigerants to replace existing refrigerants

Available cooling agent	**Recommended refrigerants**	
	Marking	**Compound composition**
	R401A	R22/152a/124
R12	R401B	R22/152a/124
	R409A	R22/124R142b
R500	R409B	R22/124/142b
	R413A[5]	R134a/218/600a
R502	R22	---
	R402A	R22/125/290
	R402B	R22/125/290
	R403A	R22/218/290
	R403B	R22/218/290
	R408A	R22/143a/125
R114	R124[3]	-------
R12B1	R142b[1,3]	-------
R13B1, R13 və R503	Recommended alternatives to this group are in the following table.	

Table 2. Refrigerants that can be used instead of CFC and HCFC containing agents

Available cooling agent	**Recommended refrigerants**	
	Marking	**Compound composition**
R12 R500	R134a	
R502	R404A	R143a/R125/E134a
	R507A	R143a/125
	R407A,R407B	R32/125/134a
R22	R407C	R32/125/134a
	R410A[3]	R32/125
	R417A	R125/134a/600a
R114	R236fa[4]	------
R12B1	R227ea	----
R13B1	R23	---
R503	R503A	R23/116
	R503B	R23/116

Table 3. Halogen-free CFC and HCFC-containing agents can be used instead cooling agents

Available cooling agent	**Recommended refrigerants**	
	Marking	**Compound composition**
R12 R500	R290/600 a[1] R600a[1,3]	C_3H_8 / C_4H_{10} C_4H_{10}
R502	R717[1,2] R290[1] R1270[1]	NH_3 C_3H_8 C_3H_6
R22	R717[1,2] R290[1] R1270[1]	NH_3 C_3H_8 C_3H_6
R114 R12B1	R600a[1]	C_4H_{10}
R13B1	Alternativi tapılmamışdır	
R13 R503	R170[1]	C_2H_6
Various	R744[1]	CO_2

Note: The numbers above the codes in the table are: 1. Flammable, 2. Toxic, 3. with pressure and COP exchange alternative, 4. limited availability, 5. Chlorine free; shows that

CONCLUSIONS

As a result, alternative cooling agents have been proposed in tabular form, and the front-runners are listed separately below.

1. R-123 (CF3CCL2H) can be used instead of R-11(CFCl3) refrigerant. While R-11 has three chlorines, R-123 has one hydrogen atom instead of one chlorine. This lowers the value of the ozone depleting potential. In addition, R-123 has a higher boiling point and is non-toxic.

2. R22 or R134a (CF3CFH2) can be offered instead of R-12 (CF2Cl2). However, the use of R-22 will be banned after 2030. In addition, modifications should be made to the cooling system equipment. Technically, agents such as R-152a, R-401A, R-401B, R-409A, and R-409B can be used in place of R-12, but a very serious system modification change would be required.

3. The properties of R-134a are very similar to R-12 and can be easily used in the same system with simple modifications. At the same time, R-134a has zero ozone depletion potential because it does not contain a chlorine atom.

4. R-507, R-407A, R-407B, R402A, R-402B, R-404A or R-404A can be used instead of R-502 for lower temperature ranges.

5. Instead of R-22, which will be discontinued in 2030, R-290, which has zero global warming effect and ozone depletion potential, can be used. R-290 agent is a non-flammable refrigerant. Also, in this case, there is no need for any changes on the system.

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ANALYSİS BASED ON SİMULATİON MODELİNG OF THE REGİMES OF DİSTRİBUTİON ELECTRİC NETWORKS WİTH THE INTEGRATİON OF GREEN ENERGY TECHNOLOGİES

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It has been determined that the most effective model for conducting analysis of distribution electric networks' regimes through simulation modeling is the DIgSILENT PowerFactory software suite, as it allows for visual clarity and real-time research. Using this software, the load regimes of the Sarıqaya distribution network of "Azərişıq" OJSC were studied. The results showed that the loadings on most of the 6 kV feeder lines exceed permissible values, voltage drops are high, and these factors confirm a significant likelihood of accidents occurring in the network. Accordingly, proposals have been made for the reworking and redesigning of the network's topology.

Keywords: distribution electric network, DIgSILENT PowerFactory software suite, line overloads, voltage drop, voltage profile

АНАЛИЗ РЕЖИМОВ РАСПРЕДЕЛИТЕЛЬНЫХ ЭЛЕКТРИЧЕСКИХ СЕТЕЙ С ИНТЕГРИРОВАННОЙ ЗЕЛЕНОЙ ЭНЕРГОТЕХНОЛОГИЙ НА ОСНОВЕ СИМУЛЯЦИОННЫХ МОДЕЛИРОВАНИЯ

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На основе анализа возможностей различных программных комплексов по анализу режимов распределительных электросетей с помощью имитационных моделей определено, что наиболее эффективной модулью, позволяющей осуществлять наглядное и оперативное исследование, является применение программы DIgSILENT PowerFactory. С использованием этого комплекса было проведено исследование режимов нагрузки распределительной сети Сарыгая ОАО «Азеришик». Полученные результаты показали, что нагрузки большинства фидеров 6 кВ превышают допустимые значения, падения напряжения высокие, и эти условия подтверждают высокую вероятность аварийных отключение в сети. Соответственно, были сделаны предложения по переработке и проектированию топологии сети.

Ключевые слова: распределительная сеть, комплекс DIgSILENT PowerFactory, перегрузки линий, падение напряжения, профиль напряжения.

Introduction

The integration of green energy technologies through renewable sources is a priority for modern energy systems. These sources are primarily connected to distribution electric systems at lower voltage levels [1-4]. At the same time, considering modern challenges, the issues of improving or reconstructing existing distribution networks are brought to the forefront, and various

approaches can be used to address the emerging problems. First and foremost, the adoption of effective decisions regarding both existing and proposed options requires conducting thorough regime studies. Performing these regime studies through simulation models is advantageous.

The application of simulation modeling in power systems is a visual method that involves creating mathematical models of electric networks based on a systematic approach, and using these models to simulate their operating regimes [5-7]. Simulation modeling techniques are considered crucial tools in various fields, such as the design, analysis, and management of power systems. Therefore, the use of simulation software for forecasting, optimizing, and managing regimes in power systems is regarded as a priority. These programs are also essential virtual tools for analyzing the stability of the power system, optimizing design or operational processes, diagnosing issues, and developing solutions.

Simulation software in power systems allows for modeling the processes of electricity generation, transmission, and distribution, enabling the analysis of the system's performance mechanisms. These analyses are used to identify the overall state of the energy system by determining significant regime parameters such as voltage drop, active and reactive power losses, non-sinusoidal and non-symmetric regimes, and power distribution.

One of the key issues in power systems is assisting in the optimization of power system design. Simulations are conducted to improve the system's performance and increase its efficiency by altering various components and parameters. This is crucial for reducing investment costs, minimizing power losses, and ensuring safety. Additionally, simulation software helps optimize the operational processes of power systems. For example, system and network operators can manage energy generation and transmission in the most efficient and safe manner through real-time simulations. Moreover, simulations are also used for planning, balancing loads, and ensuring system stability during fault conditions.

Moreover, simulation software is one of the most effective tools for diagnosing and resolving potential issues in power systems. In complexly configured power systems, simulations can identify the type of fault based on its cause and allow for the necessary corrections to be implemented. Additionally, simulations can be used to analyze and resolve other issues such as energy imbalance, trends in regime parameters, voltage non-sinusoidality, and voltage drop [8]. This work examines the analysis of the regimes of distribution electric networks based on simulation models.

1. Comparative Analysis of Simulation Modeling in Power Systems

Simulation software plays a fundamental role in power systems. These programs contribute to the creation of more efficient, safe, and sustainable energy systems by being utilized in various areas such as power system analysis, design, operational optimization, problem diagnosis, and solution development. The use of simulation software in power systems is crucial for several important reasons:

1.1. **Design and Planning**: Simulations are used to evaluate different design options and predict the resilience capabilities of systems when creating a new power system. This can help reduce financial costs and identify systems that offer the best efficiency.

1.2. **Risk Mitigation**: Simulations reduce risks by testing potential scenarios before making changes to real systems. This is used to identify and prevent possible faults in the systems.

1.3. **Performance Evaluation**: Simulations are used to analyze and improve the performance of existing systems. Based on the data obtained, it is possible to predict how systems will operate and identify opportunities for development.

1.4. **Training and Learning Tools**: Simulations are used as training tools for engineers and students. They provide practical experience and the opportunity to apply theoretical knowledge by simulating real-world scenarios.

1.5. **Innovations and Developments**: Simulations are used to test the integration of new technologies or changes into real systems. This is important for understanding how systems can adapt to future demands.

Simulation software is a powerful tool for understanding the effects of changes in power systems in advance, reducing costs, mitigating risks, and enhancing performance. These programs facilitate the understanding of complex systems and contribute to the creation of more effective, reliable, and sustainable energy systems.

Reliability analysis plays a significant role in ensuring the resilience of power systems. This analysis is used to measure a power system's ability to operate reliably and sustainably over a specific period. The role of reliability analysis in energy systems can be summarized as follows:

a) **Reduction of Outage Duration**: Simulated analysis assesses the potential to reduce the duration of outages in the system. This also minimizes power interruptions and system failures, thereby enhancing the system’s capability to provide continuous electricity.

b) **Risk Assessment**: This simulation tool identifies and analyzes potential risks and failures. It helps in the early detection of vulnerabilities and potential hazards within the system.

c) **Determination of Maintenance and Rehabilitation Strategies**: Reliability analysis plays a crucial role in identifying maintenance and repair requirements for system components. It helps in developing preventive maintenance strategies to ensure the system operates seamlessly for longer periods.

d) **Investment Decisions**: The results of the analysis guide improvements and investments in the system. It assists in making the most effective and efficient investment decisions to enhance system reliability.

e) **Emergency Management and Planning**: Reliability analysis is a key component of emergency planning. It ensures the simulation of potential scenarios and the development of intervention strategies for these scenarios.

These analyses are used to ensure that energy systems operate more safely, sustainably, and reliably. Reducing outages, minimizing risks, and strengthening the system are critical issues. Simulation software used in power systems is a key tool for the organization, analysis, and optimization of distribution networks. These programs are primarily utilized by electrical engineers and are widely employed in various institutions such as power supply companies, research institutions, and universities.

Currently, various types of simulation software are in use. Among them are PSS/E (a very popular simulation program for the planning and analysis of power transmission and distribution systems. It includes many important features such as ensuring uninterrupted power supply, voltage and frequency control, reactive power loss, and more), ETAP (an advanced electrical analysis program for power systems. It allows electrical engineers to organize, analyze, and optimize energy

systems. ETAP includes a wide range of features such as AC/DC analysis, short-circuit calculations, harmonic analysis, protection analysis, and optimization), DIgSILENT PowerFactory (a widely used simulation program for power system analysis and optimization. This program enables various analyses such as voltage drop analysis, short-circuit analysis, energy balance analysis, harmonic analysis, dynamic simulations, and protection selectivity), EMTP-RV (a simulation program used for electromagnetic transient and harmonic analysis in power systems), and PowerWorld Simulator (a program used for the design, analysis, and simulation of power systems. This program has many features including power analysis, reactive power management, voltage control, stability analysis, and resource planning).

The simulation programs listed above possess the capability to analyze and optimize various aspects of power systems. Additionally, within this category, there are numerous other simulation programs, each tailored with specific features to meet particular requirements. The accuracy and reliability of a power system simulation depend on several factors, including the quality of input data, the precision of mathematical models, and the accuracy of the simulation algorithm. When all these factors are taken into account, the simulation results in power systems generally provide a reliable visualization of the real situation and offer credible predictions. However, the accuracy of simulation results may be influenced by factors that cannot be fully replicated (such as the physical condition of the network, unexpected events, or changes over time). Therefore, simulation results may not always yield completely accurate outcomes and may require validation and verification against real-world conditions.

In conclusion, to rely on simulations in power systems, it is crucial to input accurate data, use precise mathematical models, and apply correct simulation algorithms. Additionally, comparing and validating simulation results against real-world conditions is necessary. By doing so, simulations conducted on electrical systems can make design, analysis, and management processes more effective and reliable.

2. The Mathematical Model of the Regime Report of the Transmission Network

In general, the following system of nonlinear equations is used in the study of regimes in electrical engineering: [9]:

$$\left.\begin{aligned} \Delta P\left(\delta,\ P_s, \left|U_{наг}\right|,\ Q_g\right) &= P_i^{sp} - \left|U_i\right| \cdot \sum_{j=1}^{N} \left|U_j\right| \cdot \left(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}\right) = 0,\ \ \forall i \in N \\ \Delta Q\left(\delta,\ P_s, \left|U_{наг}\right|,\ Q_g\right) &= Q_i^{sp} - \left|U_i\right| \cdot \sum_{j=1}^{N} \left|U_j\right| \cdot \left(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij}\right) = 0,\ \forall i \in n_{pa} \end{aligned}\right\} \qquad (1)$$

Here, $\Delta P,\ \ \Delta Q$ - are the nonlinear difference functions of active and reactive power injections at node i; $P_i^{sp},\ Q_i^{sp}$ - are the specified values of active and reactive power injections at node i; $\delta -$ is the angle of the voltage vector at the node; $P_s -$ is the generation active power at the slack bus; $Q_g -$ generation reactive power at the PU nodes; $\left|U_{наг}\right| -$ voltage at PQ nodes; $\left|U_i\right| -$ voltage at $i -$ nodes; $\delta_{ij} -$ the angle between the voltage vectors of buses i and j; $G_{ij}, B_{ij} -$ the real and imaginary parts of the admittance matrix; $N -$ the number of nodes.

Equations (1) and (2) can be written in vector form as follows:

$$f(x) = \begin{bmatrix} \Delta P(\delta, P_s U_{PQ}, Q_g) \\ \Delta Q(\delta, P_s, U_{PQ}, Q_g) \end{bmatrix} = 0 \tag{2}$$

Since it is not directly possible to obtain multiple solutions simultaneously based on equation (3), the problem is solved iteratively with the help of known methods. For example, using the Newton-Raphson method, the problem can be solved by linearizing equations (1) and (2):

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = [J] \begin{bmatrix} \Delta \delta \\ \Delta P_s \\ \Delta U_{PQ} \\ \Delta Q_g \end{bmatrix} \tag{3}$$

Here, $[J]-$ is the Jacobian matrix, which, as is well known, is written as follows [10,11]:

$$[J] = \begin{bmatrix} \dfrac{\partial P}{\partial \delta} & \dfrac{\partial P}{\partial P_s} & \dfrac{\partial P}{\partial U_{PQ}} & \dfrac{\partial P}{\partial Q_g} \\ \dfrac{\partial Q}{\partial \delta} & \dfrac{\partial Q}{\partial P_s} & \dfrac{\partial Q}{\partial U_{PQ}} & \dfrac{\partial Q}{\partial Q_g} \end{bmatrix} \tag{4}$$

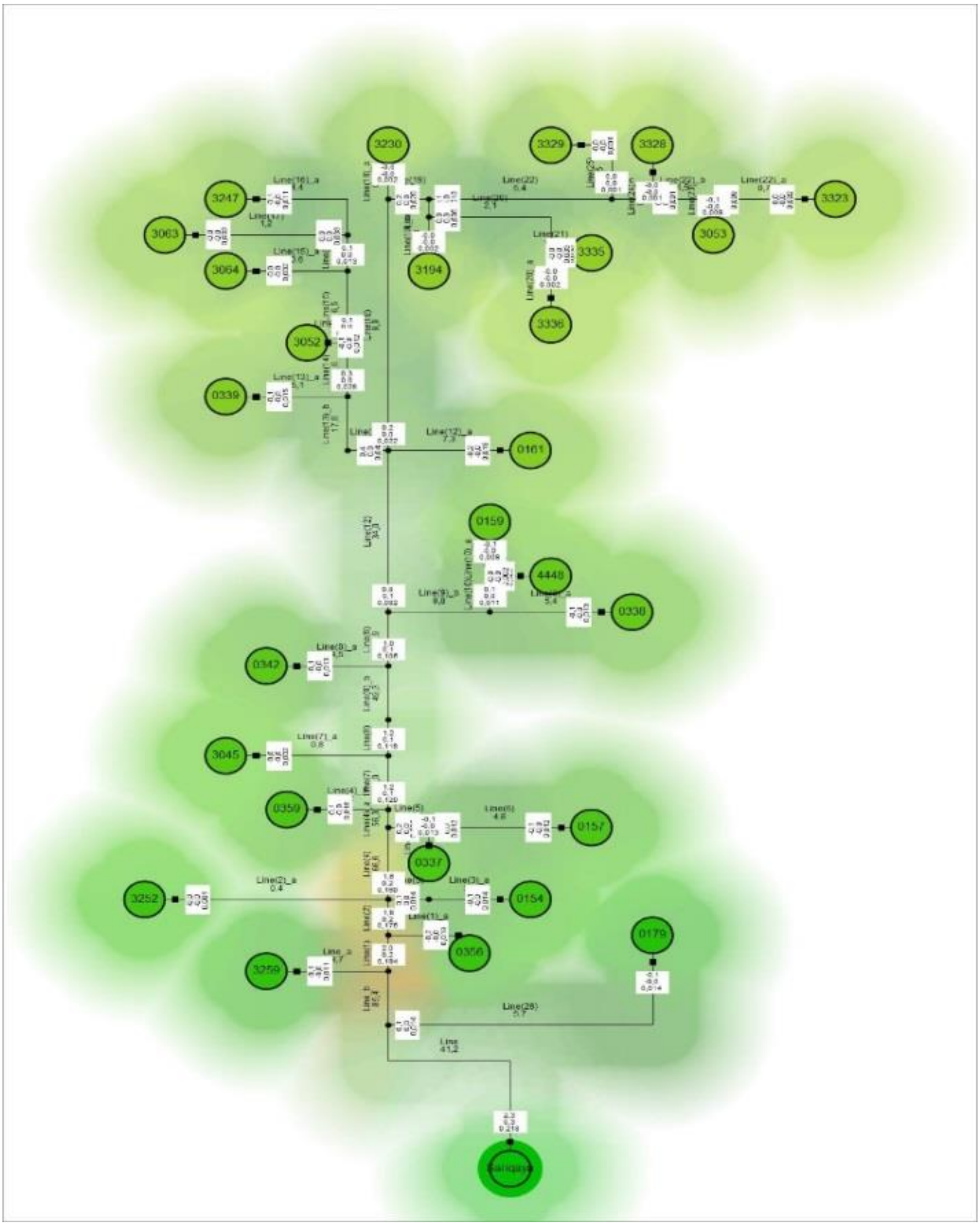
Thus, in the considered case, the study of the regimes of the distribution network will be carried out using the DIgSILENT PowerFactory suite based on the (1)-(4) algorithm.

3. Investigation of the Determined Modes of the Distribution Network

3.1. Investigation of the Current Determined Mode of the Distribution Network

Currently, several identified issues within the distribution networks of Azerbaijan's power system operator remain unresolved [12-16]. These issues include the improper design of new stations and substations, voltage drops exceeding acceptable levels, and the continued use of outdated electrical equipment. To address these problems, simulating and creating mathematical models for the equipment that will be replaced during reconstruction work is essential. For instance, using the "DIgSILENT PowerFactory" software, analyses of the load and voltage profiles of the 11.2 km long 6 kV "Novxanı - 1 H/X" feeder supplied by the 35/6 kV "Sarıqaya" substation were conducted. Active and reactive power losses were calculated, and simulations for reconstruction work on the feeder were performed. Several loading conditions were examined in the simulation: normal mode, 50%, and 70% overload conditions.

In Fig. 1, the simulation model of the load analysis for the 6 kV Novxanı-1 feeder (a) and the feeder's integration scheme into the GIS (b) are presented. As shown in Pic. 1a, the distribution network has multiple branches along its length, and the 6/0.4 kV transformer stations exhibit low load conditions (up to 10%). Even under normal load conditions, some elements might experience overloads (as depicted in Fig. 1b). These situations necessitate the implementation of appropriate maintenance, reconstruction, and improvement measures to enhance the efficiency of the network's operating modes.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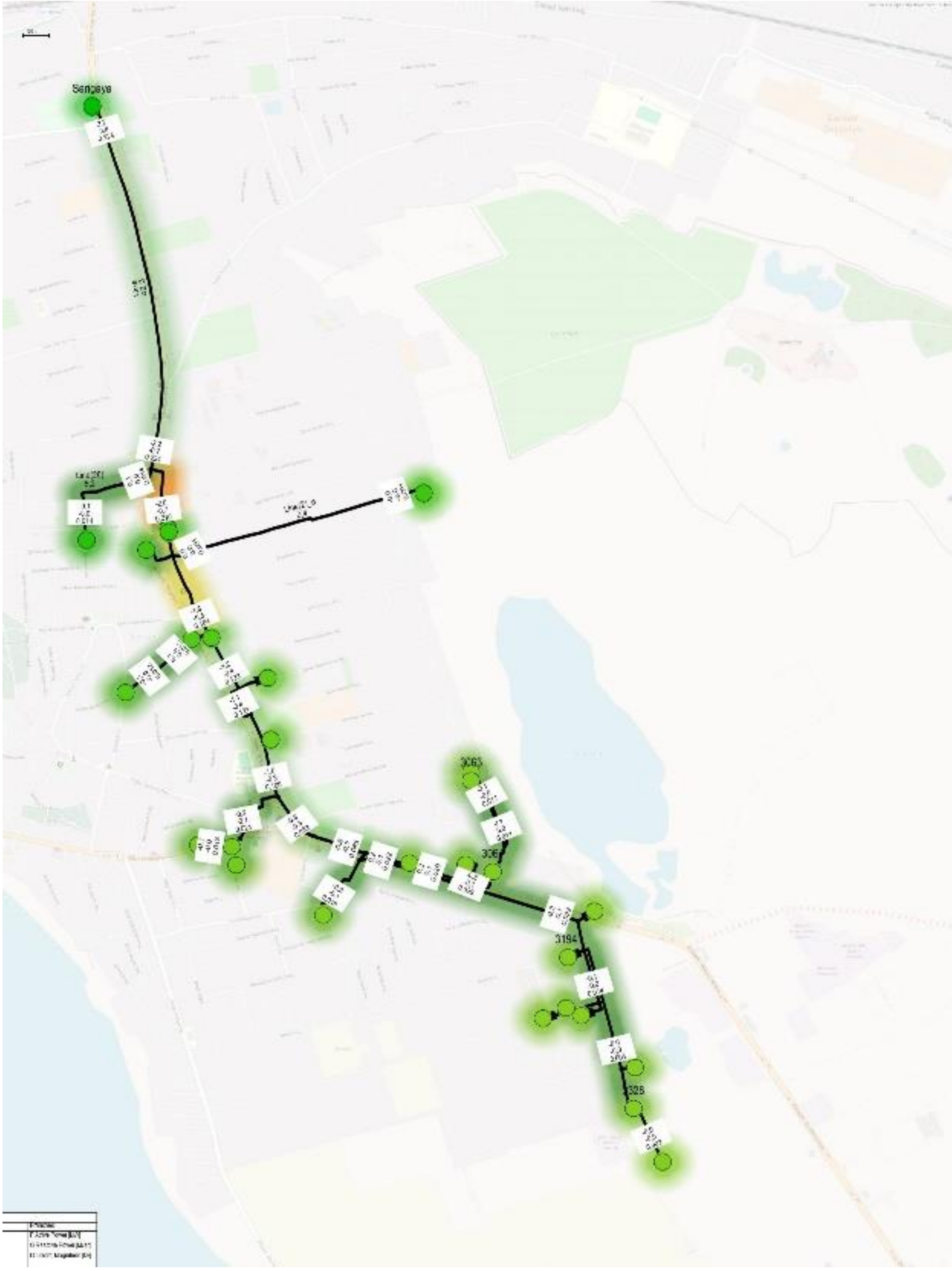


b)

Fig. 1. The simulation model of the 6 kV “Novxanı-1” feeder:
a) Model of load analysis in the determined regime of the feeder; b) Integration of the mathematical model of load analysis in the determined regime of the feeder into the Geographic Information System (GIS)."

To investigate the aforementioned issues, a simulation model of the distribution network is used to conduct regime studies. First, let's examine the calculated and experimental results based on

the simulation model for the 17-branched 6 kV feeder under normal steady-state conditions. Table 1 presents the voltage levels for the Novxanı-1 6 kV feeder line in the Sarıqaya network district under normal operating conditions.

In the determined regime, the voltage at the final transformer substation of the feeder has experienced a voltage drop of ΔU=7%.

Table 1. The values of voltage in the determined regime of the feeder

Fider	Dis. Network	Nominal Voltage, V	Voltage value, kV	Voltage value i, n.v.	U, angle, dig
0159	Sariqaya	6000,0	5,7	0,942	-1,4
0338	Sariqaya	6000,0	5,7	0,942	-1,4
0161	Sariqaya	6000,0	5,6	0,936	-1,5
0339	Sariqaya	6000,0	5,6	0,936	-1,5
3052	Sariqaya	6000,0	5,6	0,936	-1,6
3064	Sariqaya	6000,0	5,6	0,935	-1,6
3063	Sariqaya	6000,0	5,6	0,934	-1,6
3247	Sariqaya	6000,0	5,6	0,934	-1,6
3230	Sariqaya	6000,0	5,6	0,934	-1,6
3194	Sariqaya	6000,0	5,6	0,933	-1,6
3329	Sariqaya	6000,0	5,6	0,933	-1,6
3328	Sariqaya	6000,0	5,6	0,933	-1,6
3323	Sariqaya	6000,0	5,6	0,933	-1,6
3335	Sariqaya	6000,0	5,6	0,932	-1,6
3053	Sariqaya	6000,0	5,6	0,932	-1,6
3336	Sariqaya	6000,0	5,6	0,932	-1,6

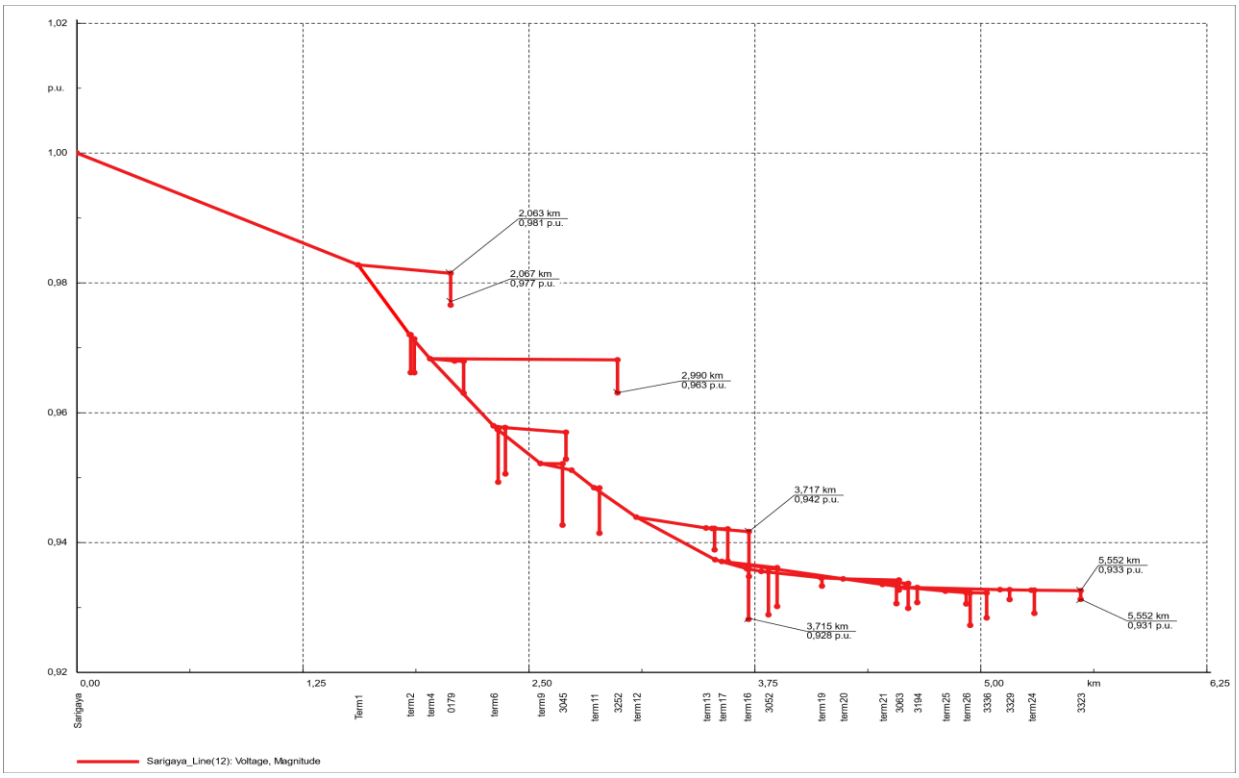


Fig 2. Voltage Profile Along the Novxanı-1 Feeder Line Under Current Steady-State Conditions

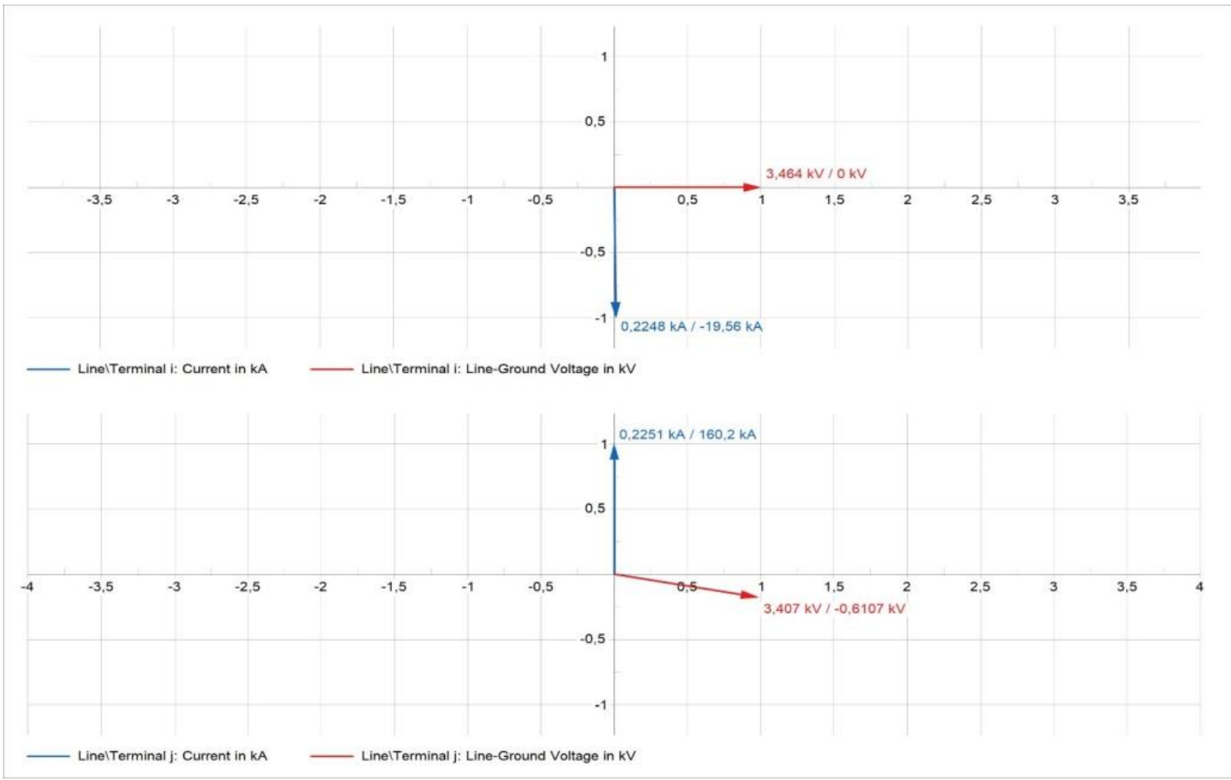


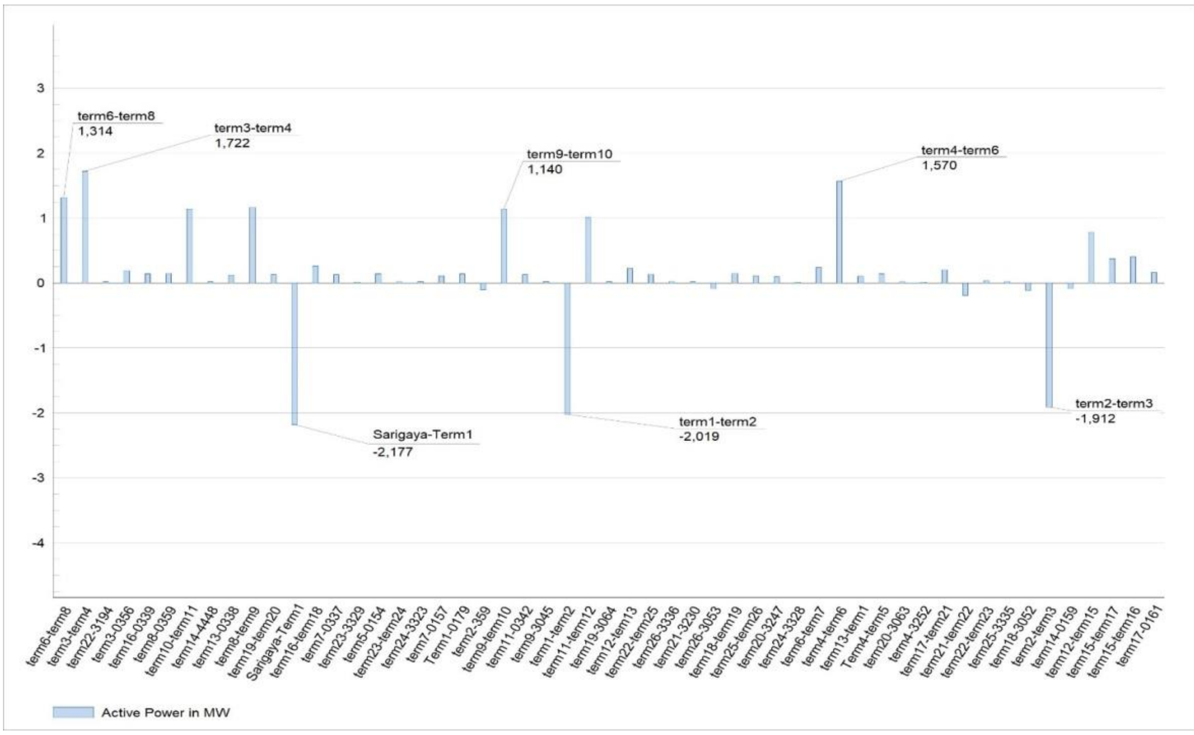
Fig. 3. Voltage and Current Vector Diagrams of the Feeder

The loadings of the 6 kV feeder lines are examined (Table 2). As shown, the loadings of individual branches vary between 23% and 88%. For example, the load of the term9-term10 branch is minimal at 23%, while the term1-term2 branch has a load of 88%. In other words, the loadings along the feeder vary, leading to a wide range of voltage drops. As a result, the voltages at the demand nodes fluctuate within limits, often falling below the nominal threshold. In Figure 2, the values of the voltage and current phase angle deviations are illustrated. The diagrams indicate that the nature of the load is diverse, which can result in a reactive power factor exceeding the required norms, thereby reducing the efficiency of the network.

Table 2. The loading levels of the Sarıqaya distribution network feeder lines.

Name	Name	Loading, %	Current value, kA
term1-term2	Sariqaya	88,0	0,211
term2-term3	Sariqaya	83,4	0,200
term3-term4	Sariqaya	75,1	0,180
term4-term6	Sariqaya	68,7	0,165
term6-term8	Sariqaya	58,1	0,139
term8-term9	Sariqaya	51,5	0,124
term10-term11	Sariqaya	50,8	0,122
term11-term12	Sariqaya	45,2	0,108
Sarigaya-Term1	Sariqaya	42,5	0,225
term12-term15	Sariqaya	35,0	0,084
term9-term10	Sariqaya	23,0	0,122

If we examine the current loading regime of the feeder, we observe that the AS-50 line between two branches is loaded up to 88% of its nominal capacity in the established regime. In Pic 4, diagrams of active (a) and reactive (b) power demand in the current established regime are depicted. As shown, in some nodes, the reactive/active power ratios (reactive power factor) are within the range of 0.35 to 0.365. The high demand for reactive power leads to significant power and voltage losses, resulting in an inefficient regime. Specifically, the active power loss is 106 kW, and the reactive power loss is 259 kVAr.



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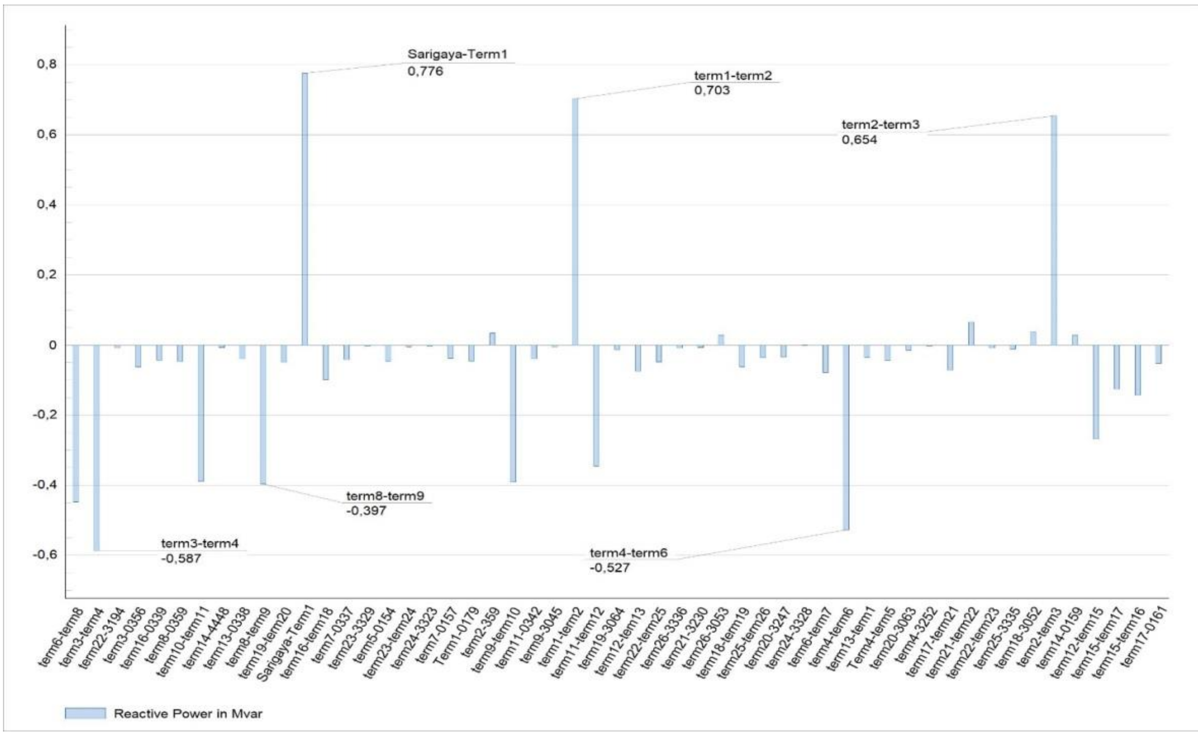


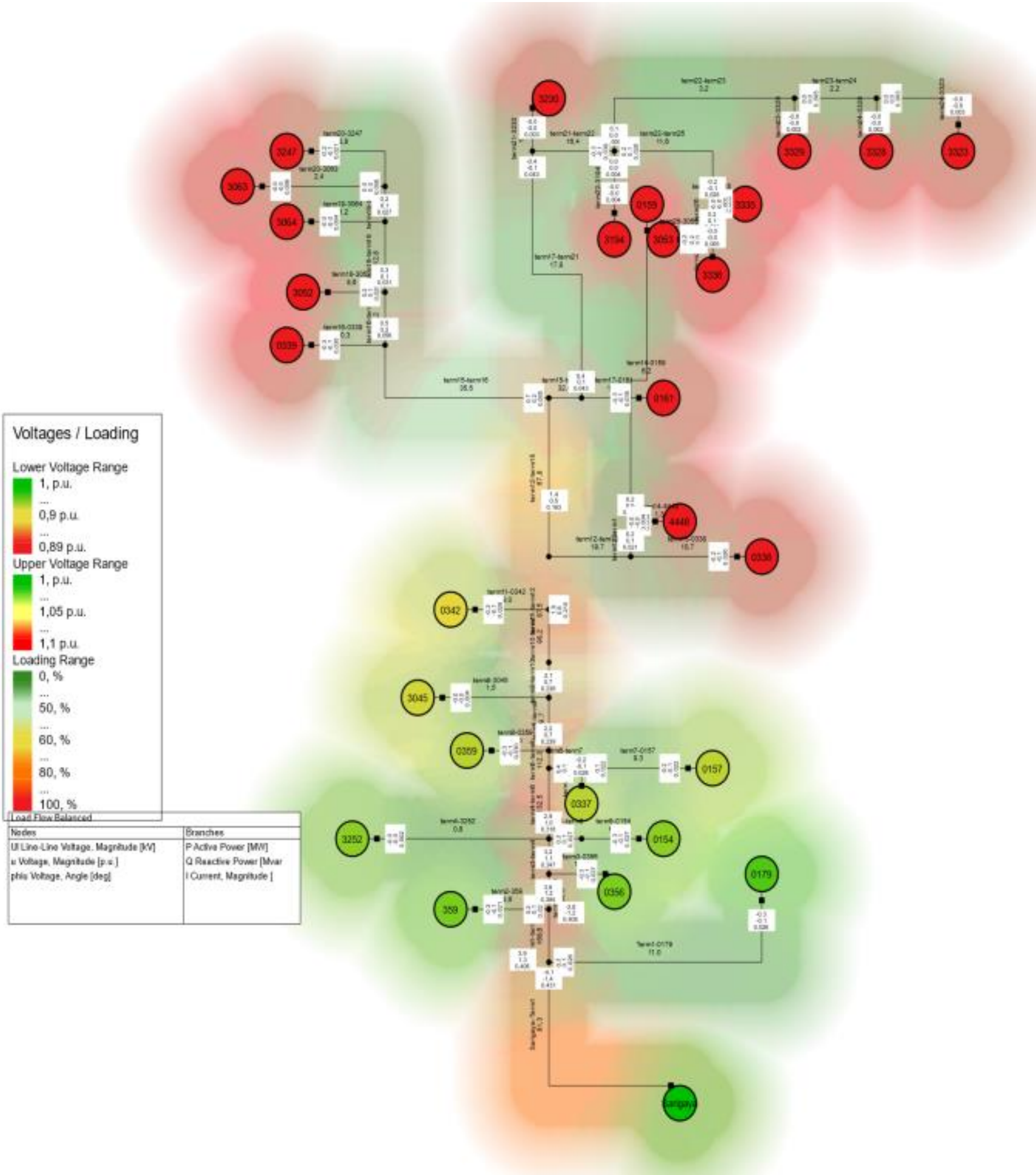
b)

Fig. 4. Active (a) and Reactive (b) Power Demands of Feeder Nodes

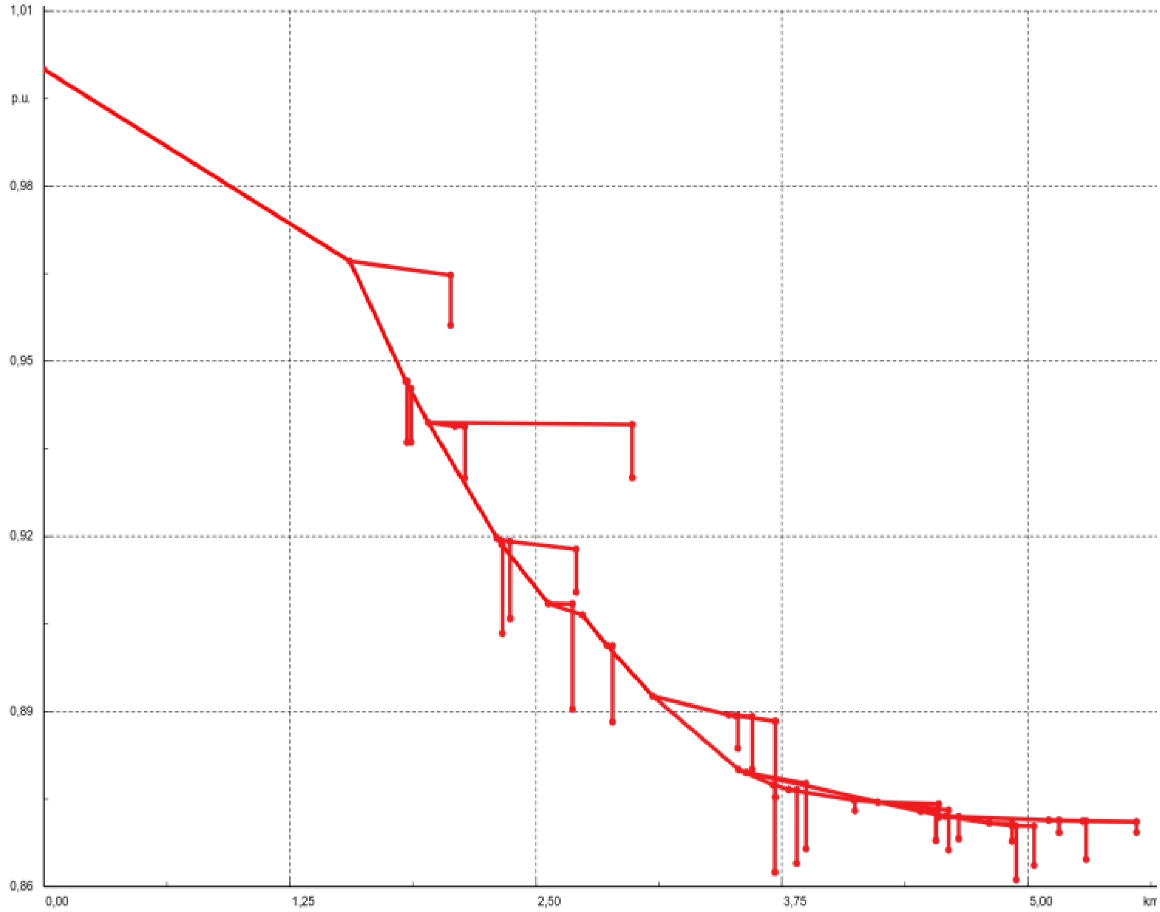
3.2. Simulation Study of Overload Regime

Considering the demographic growth, it is anticipated that this load will increase by 50% compared to the current situation. Therefore, a 50% overload scenario for the feeder was simulated (Fig. 5). From Fig. 5, it is evident that the probability of overloading in the 6 kV distribution network feeder line branches is significantly high (Fig. 5a), and the values of voltage drops in 17 nodes exceed the permissible limit (Picture 5b), in other words, they exceed 11%. In this regime, we

can observe that the voltage drop at the end point fed by the feeder increases by up to 13%. Additionally, the voltage vector angle shifts by 22.23°, and the current vector angle shifts by 0.15°.



a)



b)

Fig.5. The overloadings of the feeder lines in the distribution network.
a – The loadings of the feeder lines.; b - The voltage-distance dependency profile of the feeders.

The 240 A nominal overhead line being overloaded by 68.6% beyond its maximum rating can lead to a decrease in electricity quality and cause disruptions and failures in power transmission. This issue is primarily related to the non-compliance of the feeders' cross-sections and lengths with standards, highlighting the importance of implementing appropriate measures for the modernization of the network.

Table 3 presents the voltage values at the 6 kV nodes.

Table 3**.** Table of Voltage Values at 6 kV Nodes

Name	**Network**	**U_{nom}, kV**	**U, kV**	**U, p.u.**	**U, dig**
3323	Sariqaya	6,0	5,3	0,876	-6,4
3328	Sariqaya	6,0	5,3	0,877	-6,3
3329	Sariqaya	6,0	5,3	0,878	-6,3
3335	Sariqaya	6,0	5,3	0,880	-6,2
3336	Sariqaya	6,0	5,3	0,880	-6,2
4448	Sariqaya	6,0	5,5	0,915	-4,9

It appears that the voltage values vary within the $(0{,}876-0{,}915)\cdot U_{nom}$ limits and are significantly below the standard norms..

In Fig 6, the voltage and current vector diagrams of the feeder are depicted. As seen in the figure, it is determined that in this regime, the voltage drop at the final node supplied by the feeder increases by up to 13%. Additionally, the voltage vector angle shifts by 22.23°, and the current vector angle shifts by 0.15°. Since the current vector lags behind the voltage, it is evident that the load is characterized by a reactive nature. This indicates an increase in the reactive power demand of the electrical equipment within the consumers, which is further explained by the feeder's cable line configuration and its loading capacity.

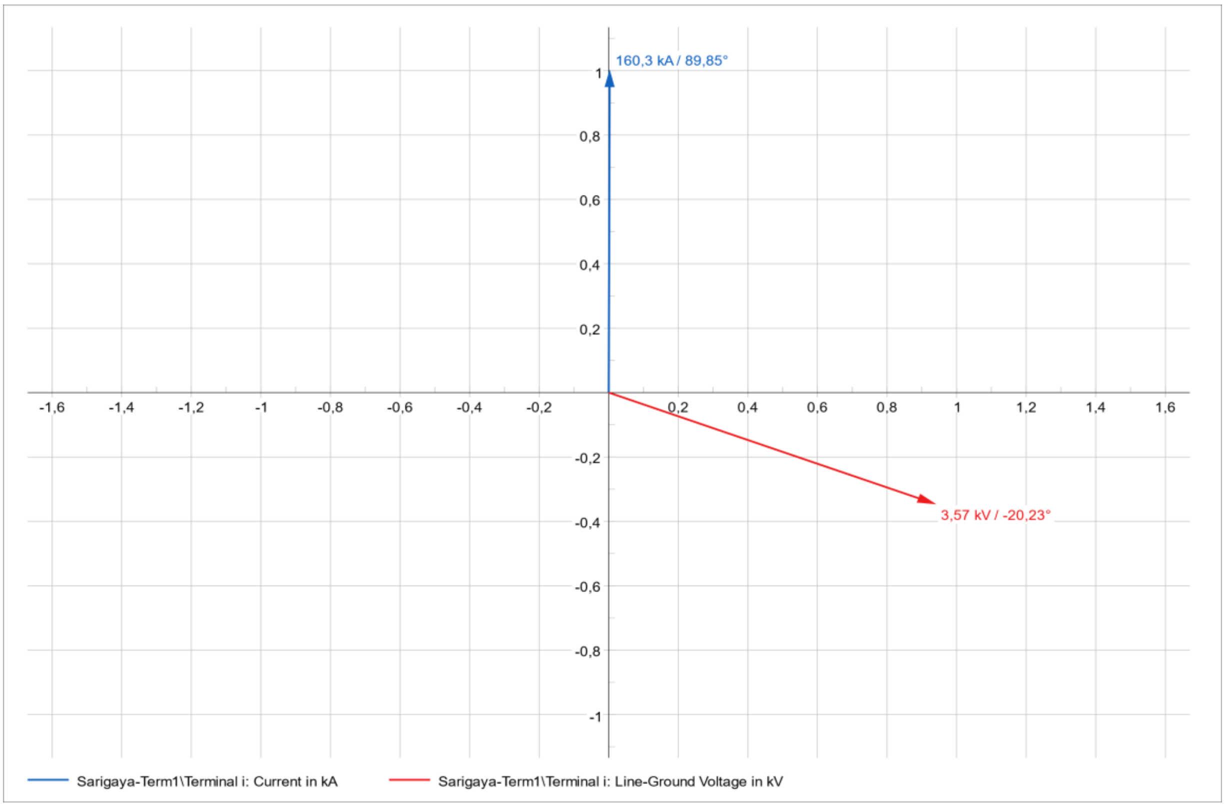


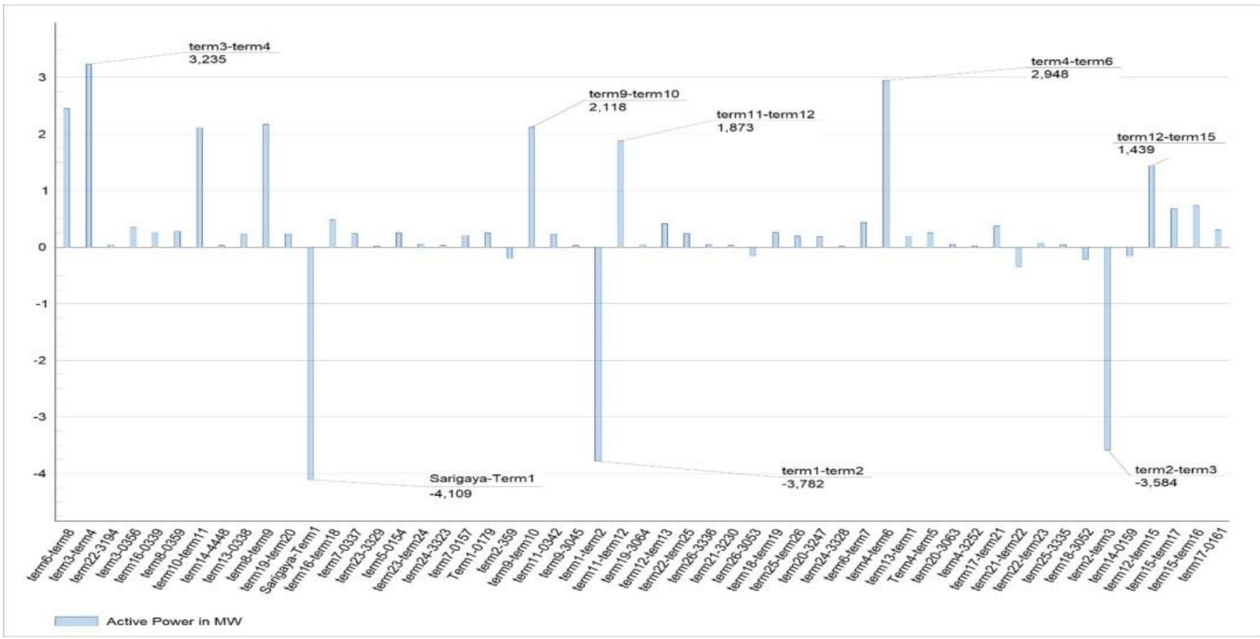
Fig 6. Diagram of the phase angle shifts of voltage and current for the feeder.

The values of the loads for the feeder and its branches are provided in Table 4.

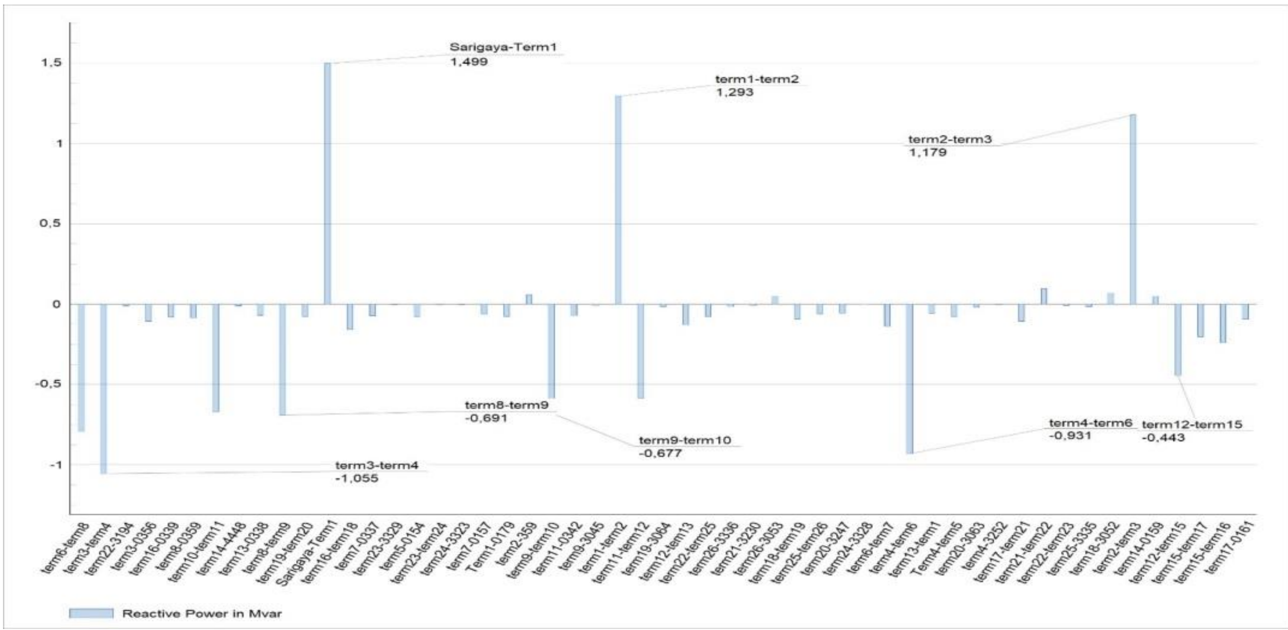
Table 4. The loads of the feeder and its branches

Name	Dis. Network	Nominal Load, %	Real Load, kA
term1-term2	Sariqaya	168,6	0,405
term2-term3	Sariqaya	160,0	0,384
term3-term4	Sariqaya	144,5	0,347
term4-term6	Sariqaya	132,5	0,318
term6-term8	Sariqaya	112,3	0,269
term8-term9	Sariqaya	99,7	0,239
term10-term11	Sariqaya	98,2	0,236
term11-term12	Sariqaya	87,5	0,210
Sarigaya-Term1	Sariqaya	81,3	0,431
term12-term15	Sariqaya	67,8	0,163
term9-term10	Sariqaya	44,5	0,236
term15-term16	Sariqaya	35,5	0,085

As seen in Table 4, some branch lines experience loading beyond their nominal limits, ranging from 12.3% to 68.6%. For instance, a power line with a nominal rating of 240 A is overloaded by up to 68.6% of its nominal value, which can impact the quality of electrical power and cause interruptions and faults in the electrical supply. Fig. 7 illustrates the active and reactive demands of the consumer nodes in the distribution network under a 50% overload condition.



a)



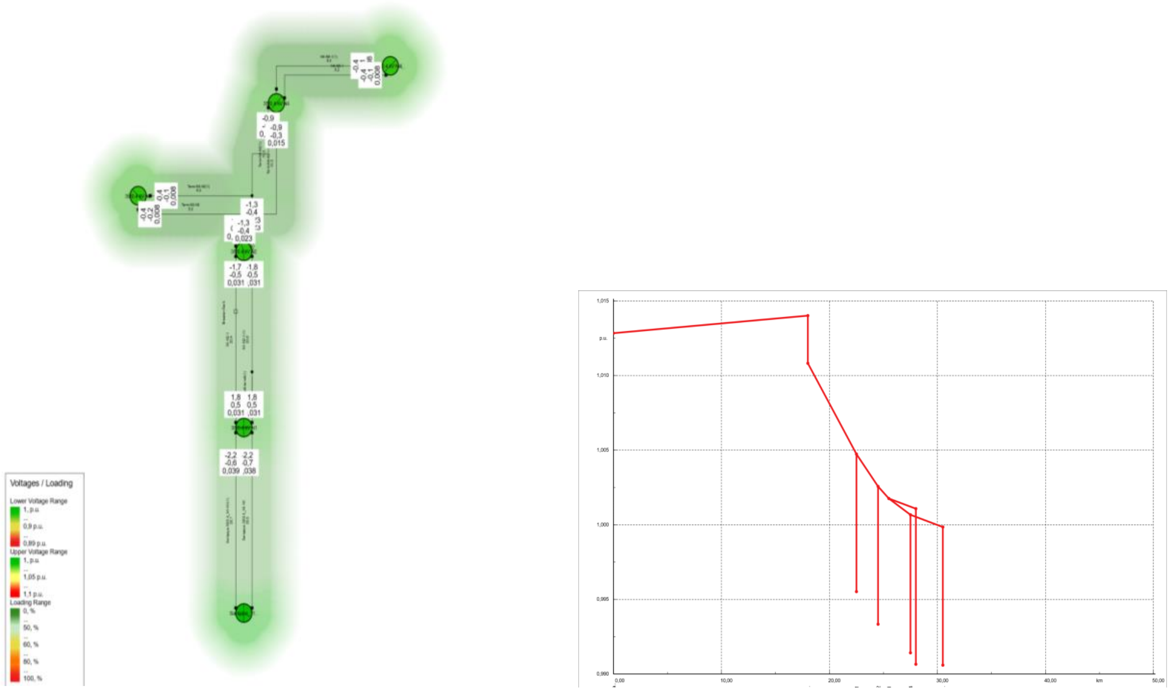
b)

Pic. 7. Diagrams of voltage and current phase angles of the feeder under a 50% overload condition

It can be seen that under a 50% overload condition, the reactive/active power ratios (reactive power factors) at the nodes of the distribution network range between 0.366 and 0.366. In this case, the high reactive power demand leads to significant power (active power loss of 366 kW, reactive power loss of 550 kVAr) and voltage losses (13.4%), resulting in an inefficient system operation.

4. Research on the Simulation Model of the Prospective Scheme of the Distribution Network

To ensure the rational operation of the examined 6 kV distribution network, various prospective scheme variants have been evaluated. The primary criteria include minimizing power losses and ensuring that voltage values at consumer nodes remain within acceptable ranges. To this end, an initial variant considered is the transition of the distribution network voltage from 6/0.4 kV to 35/0.4 kV. Fig. 7 shows the proposed scheme for the Novxanı-1 distribution network, which is fed by the 35/0.4 kV Sarıqaya substation, and the voltage profile at the nodes under normal operating conditions.



Pic. 7. Proposed scheme for Novxanı-1 distribution network with 35/0.4 kV (a) and voltage profile under normal load simulation (b).

To ensure reliable and high-quality electricity supply to the consumers in the distribution network under consideration, the proposal involves upgrading the voltage level to 35/0.4 kV and establishing new power centers. Specifically, it is suggested to replace the overloaded feeder lines with larger cross-sectional units, such as AS-50, and to create new power centers. This upgrade aims to transition the distribution network to a 35/0.4 kV voltage level, enhancing its overall efficiency and reliability.

To address the area consumers' power demand of 10.7 MVA, the existing distribution network has been proposed for replacement with 10 transformers, each with a power rating of 1250 kVA, using a dual-circuit system and five 35/0.4 kV transformer stations. Additionally, the

overhead line has been replaced with an AS-50 type overhead line. This upgrade has resulted in improved capacity and quality of the 0.4 kV distribution network. The voltage profile in normal operation is shown in Pic. 7.2, indicating that the voltage levels at the nodes are maintained within the $(0{,}99 - 1{,}012) \cdot U_{nom}$ range.

Let's look at the simulation analysis of the 35/0.4 kV distribution system. In this analysis, the 35/6 kV Sarıqaya substation has been upgraded to a 110/35 kV voltage level. The analysis was performed in two scenarios: under normal load conditions at 30% of the installed capacity and under overloaded conditions at 80% of the capacity. Table 5 provides data on the loading conditions of the lines at 30% normal loading. From the table, it can be seen that the line loads reach up to 17.9%, and the discharge capacity is high.

Table 5. Loading of Electrical Lines under Normal Loading Conditions in the Prospective Scheme

Name	**Dis. Network**	**Terminal i**	**Terminal j**	**Loading, %**	**Current, kA**
Sariqaya-35/0.4_N1-N2	Sariqaya	BB(1)	BB(3)	17,9	0,038
Sariqaya-35/0.4_N1-N1	Sariqaya	BB(2)	BB	17,8	0,037
N1-N2-2	Sariqaya	BB(1)	BB(1)	14,4	0,030
N1-N2-1	Sariqaya	BB	BB	14,3	0,030
N2-Term-N2	Sariqaya	Terminal(23)	BB(1)	10,8	0,023
Sumqayıt_qovşaq-Sariqaya_N2	Sariqaya	BB(3)	BB(1)	10,8	0,060
Sumqayıt_qovşaq-Sariqaya_N1	Sariqaya	BB(2)	BB	10,7	0,060

Fig. 8 shows the vector diagrams of voltage and current. It has been observed that the loads are predominantly of a capacitive nature.

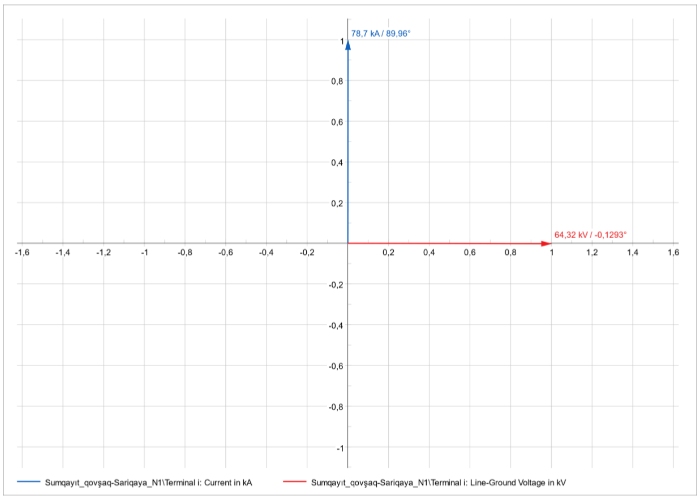
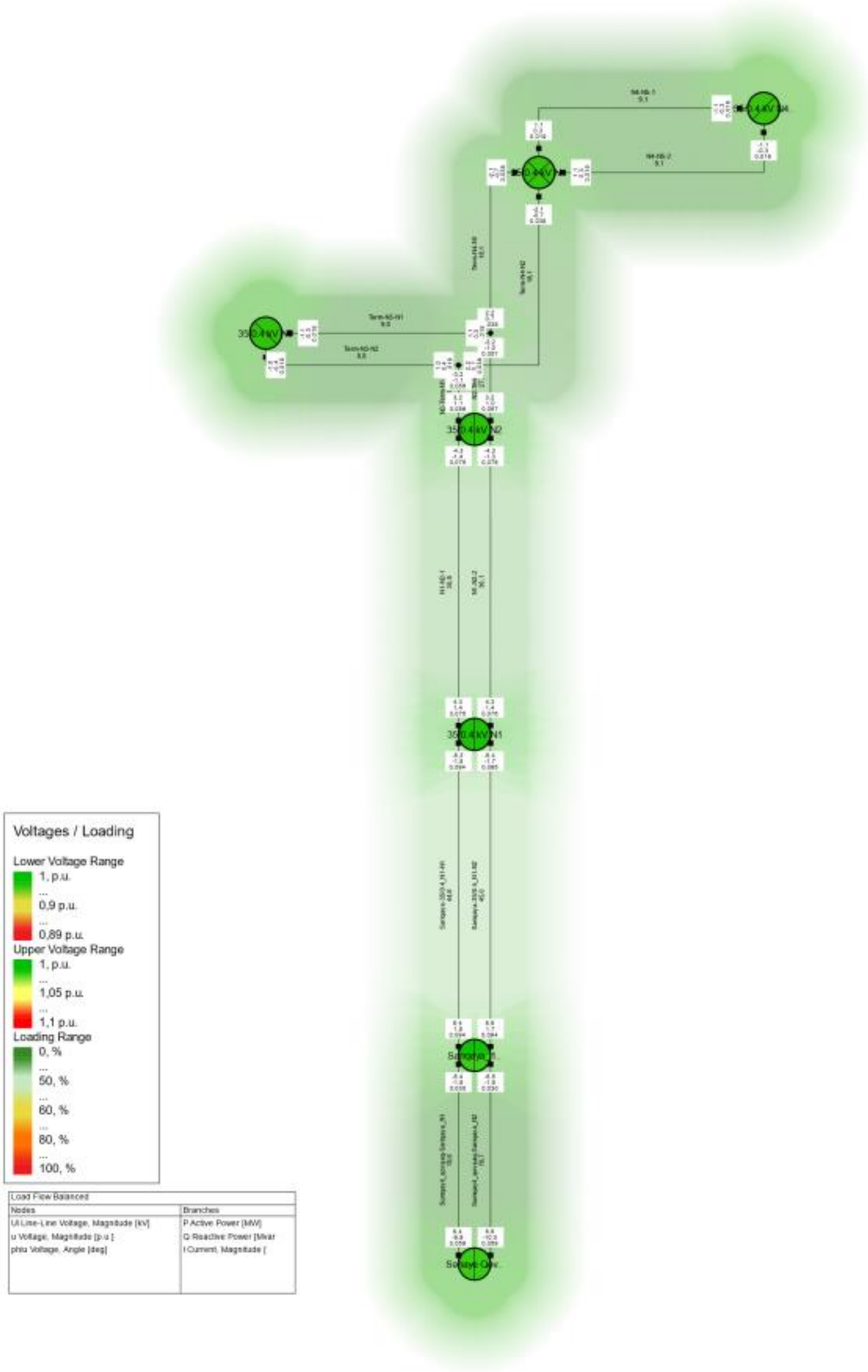
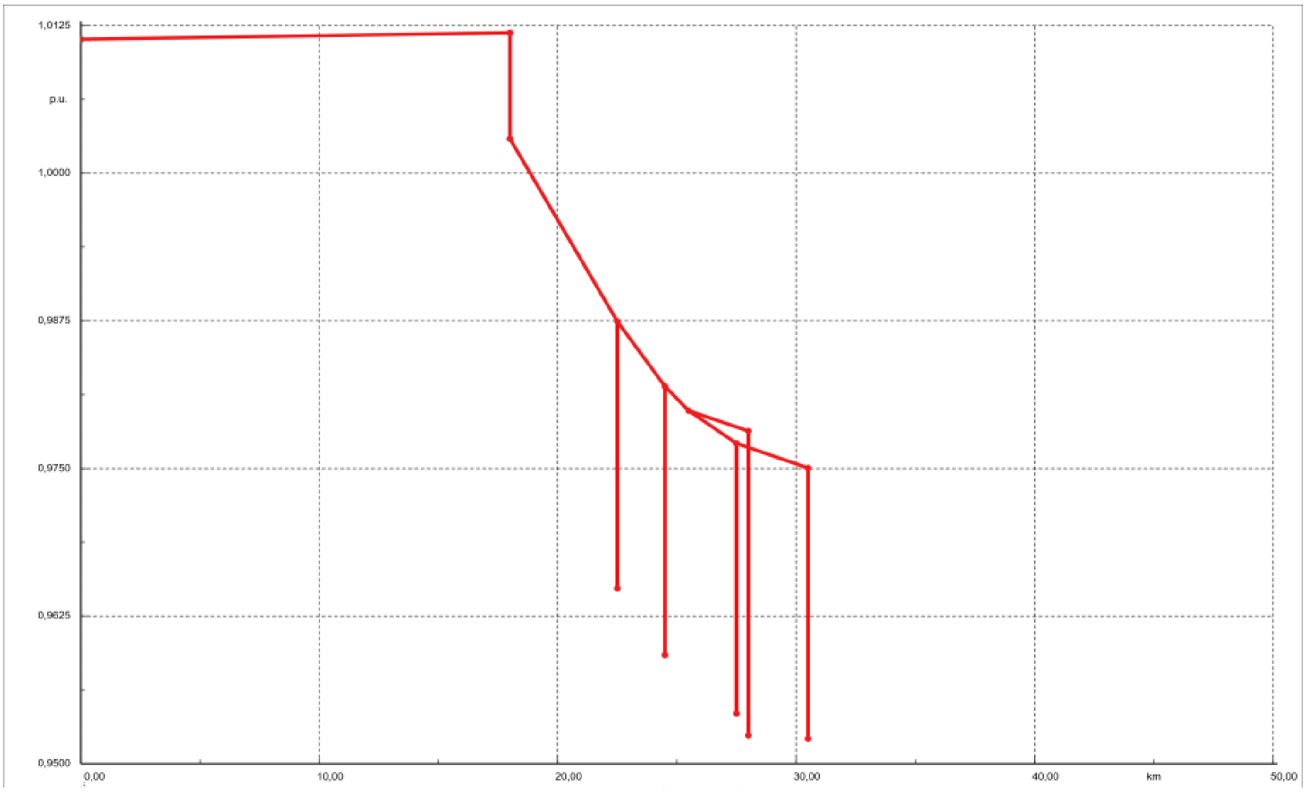


Fig. 8. Vector diagrams of voltage and current for the prospective scheme under 30% loading condition.

In Fig. 9, the simulation model of the proposed 35/0.4 kV distribution network under 80% load condition (a) and the voltage profile across the nodes (b) are depicted, with the values provided in Table 6. As can be seen, under 80% load condition, no overloading occurs in any feeder line of the network, and the voltage values are maintained within the permissible $(1{,}002-1{,}0123)\cdot U_{nom}$ interval. As observed in Table 6, the voltage values at the 35 kV nodes are maintained within the $(0{,}975-1{,}003)\cdot U_{nom}$ interval. In this case, the power loss is reduced by up to 0.05 kW, in other words, by 50%, thus achieving the efficiency of the scheme.



a)



b)

Pic. 9. The simulation scheme of the prospective distribution network under 80% load condition (a) and the voltage profile (b).

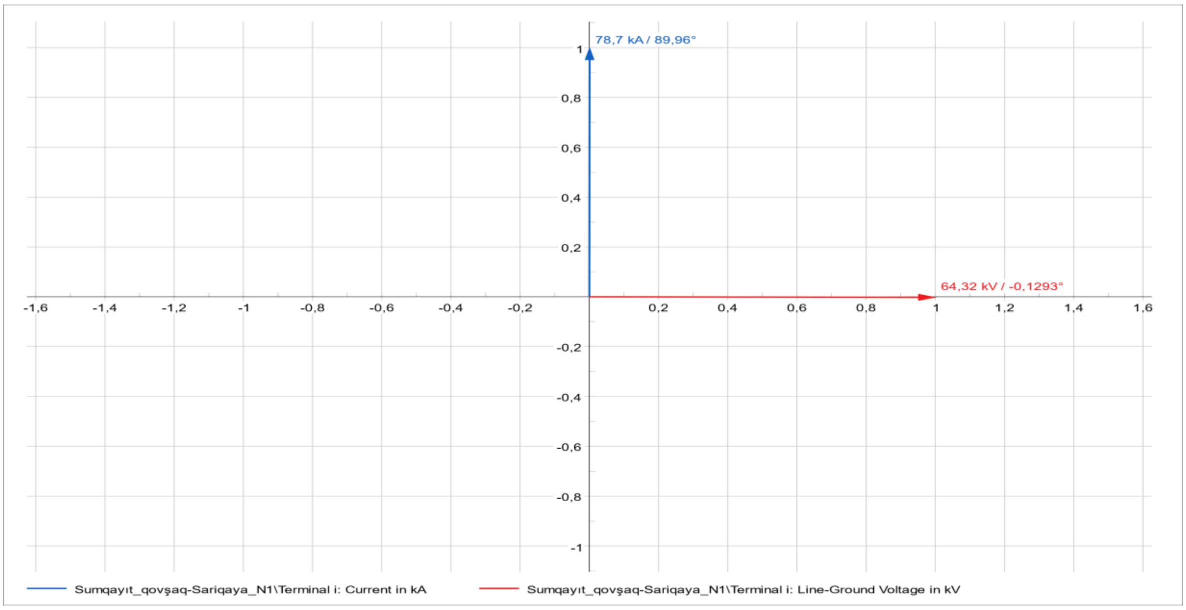
Table 6. The voltage profile at 80% load according to the prospective scheme.

Name	Network	U_{nom}, kV	U, p.u.	U, kV	U, dig
Sənaye Qovşağı	Sariqaya	220,0	1,000	220,0	0,0
Sənaye Qovşağı	Sariqaya	220,0	1,000	220,0	0,0
Sənaye Qovşağı	Sariqaya	110,0	1,011	111,2	-0,4
Sənaye Qovşağı	Sariqaya	110,0	1,011	111,3	-0,4
Sarıqaya_110_35	Sariqaya	110,0	1,012	111,3	-0,5
Sarıqaya_110_35	Sariqaya	110,0	1,012	111,3	-0,5
35/0.4 kV N4(1)	Sariqaya	35,0	0,975	34,1	-2,3
35/0.4 kV N4(1)	Sariqaya	35,0	0,975	34,1	-2,3
35/0.4 kV N4	Sariqaya	35,0	0,977	34,2	-2,3
35/0.4 kV N4	Sariqaya	35,0	0,977	34,2	-2,3
35/0.4 kV N3	Sariqaya	35,0	0,978	34,2	-2,2
35/0.4 kV N3	Sariqaya	35,0	0,978	34,2	-2,3
35/0.4 kV N2	Sariqaya	35,0	0,982	34,4	-2,2
35/0.4 kV N2	Sariqaya	35,0	0,982	34,4	-2,2
35/0.4 kV N1	Sariqaya	35,0	0,987	34,6	-2,1
35/0.4 kV N1	Sariqaya	35,0	0,988	34,6	-2,1
Sarıqaya_110_35	Sariqaya	35,0	1,003	35,1	-1,8
Sarıqaya_110_35	Sariqaya	35,0	1,003	35,1	-1,8

Table 7 presents the load levels of the electrical lines. As shown, the loading of the lines in this case does not exceed 45%. In scenarios where the load increases, in other words, under maximum load conditions, there will be no overloaded elements due to the significant reserve capacity of the lines.

Table 7. The load level of network elements under 80% load condition.

Name	Loading, %	Current, kA
Sariqaya-35/0.4_N1-N2	45,0	0,095
Sariqaya-35/0.4_N1-N1	44,8	0,094
N1-N2-2	36,1	0,076
N1-N2-1	35,8	0,075
N2-Term-N2	27,1	0,057
N2-Term-N1	26,8	0,056
Term-N4-N2	18,1	0,038
Term-N4-N1	18,1	0,038
Sumqayıt_qovşaq-Sariqaya_N2	10,7	0,059
Sumqayıt_qovşaq-Sariqaya_N1	10,6	0,059
N4-N5-1	9,1	0,019
N4-N5-2	9,1	0,019
Term-N3-N1	9,0	0,019
Term-N3-N2	8,8	0,018



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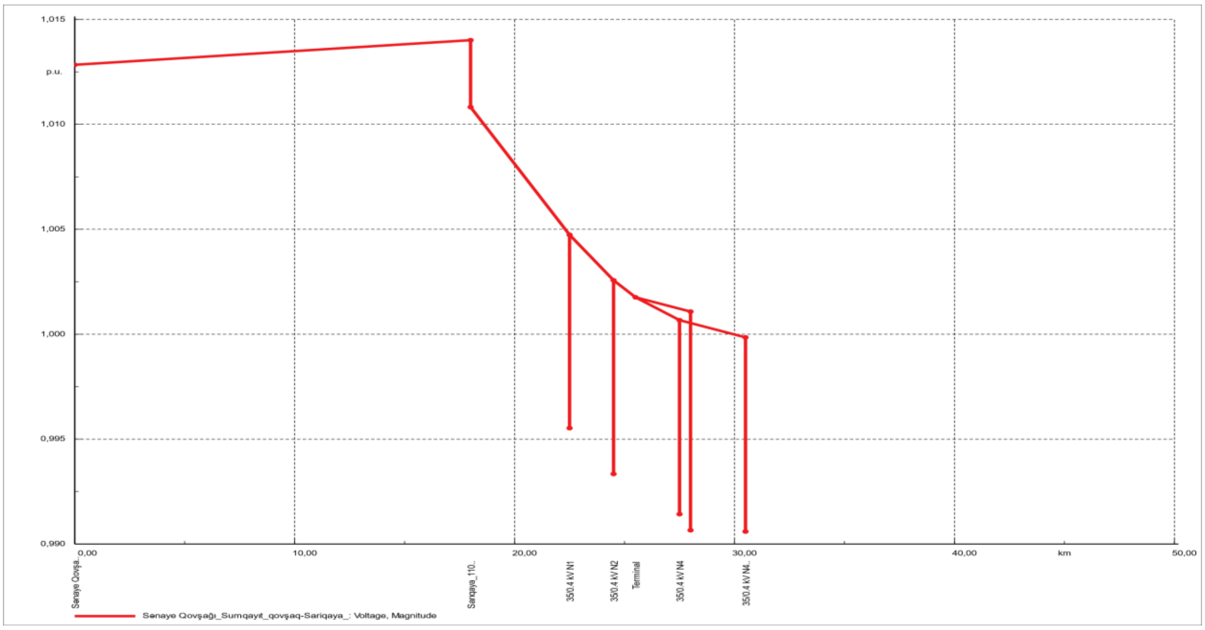


b)

Fig. 10. Active (a) and reactive (b) load diagrams of the distribution network under 80% overload condition.

In Fig.10, the active and reactive demands of the consumer nodes in the distribution network under 80% overload condition are depicted.

As shown in Pic. 10, during 80% overload, the reactive/active ratios (reactive power factor) at the nodes of the distribution network range between 0.104 and 0.441. It is evident that in this case, the demand for reactive power is high, and the power (active power loss of 340 kW, reactive power loss of 480 kVAr) and voltage losses are significant, decreasing by up to 8.3% at some consumer buses. Consequently, the regime should be considered inefficient.

3.3. Enhancing the Efficiency of the Distribution Network through the Implementation of Green Energy Technologies

Another method for improving the operational efficiency of the distribution network is the implementation of green energy technologies based on wind and solar energy sources. Given that the Absheron region is rich in wind and solar resources, the integration of these sources into the modernization of the network should be considered. Specifically, with an average annual wind speed of 8 m/s and a solar irradiance density of 1.2-1.5 kW/m² on the Absheron Peninsula, the advantages of using green technologies over the existing scheme are evident. However, it is necessary to conduct operational research and confirm the efficiency gained. To this end, the simulation model of the distribution network was used with the assistance of the DIgSILENT PowerFactory software for conducting the research.

Fig. 11 illustrates the simulation model of the integration of green technologies (a solar and a wind power plant) into the distribution network. As shown in the Figure, a 1.5 MW solar plant is connected to the 6 kV section of the Sariqaya node in the scheme, while a 2.5 MW wind plant is connected to the 6 kV node. The distribution network at the "Term11-0342" node is divided into two parts via a circuit-breaker.

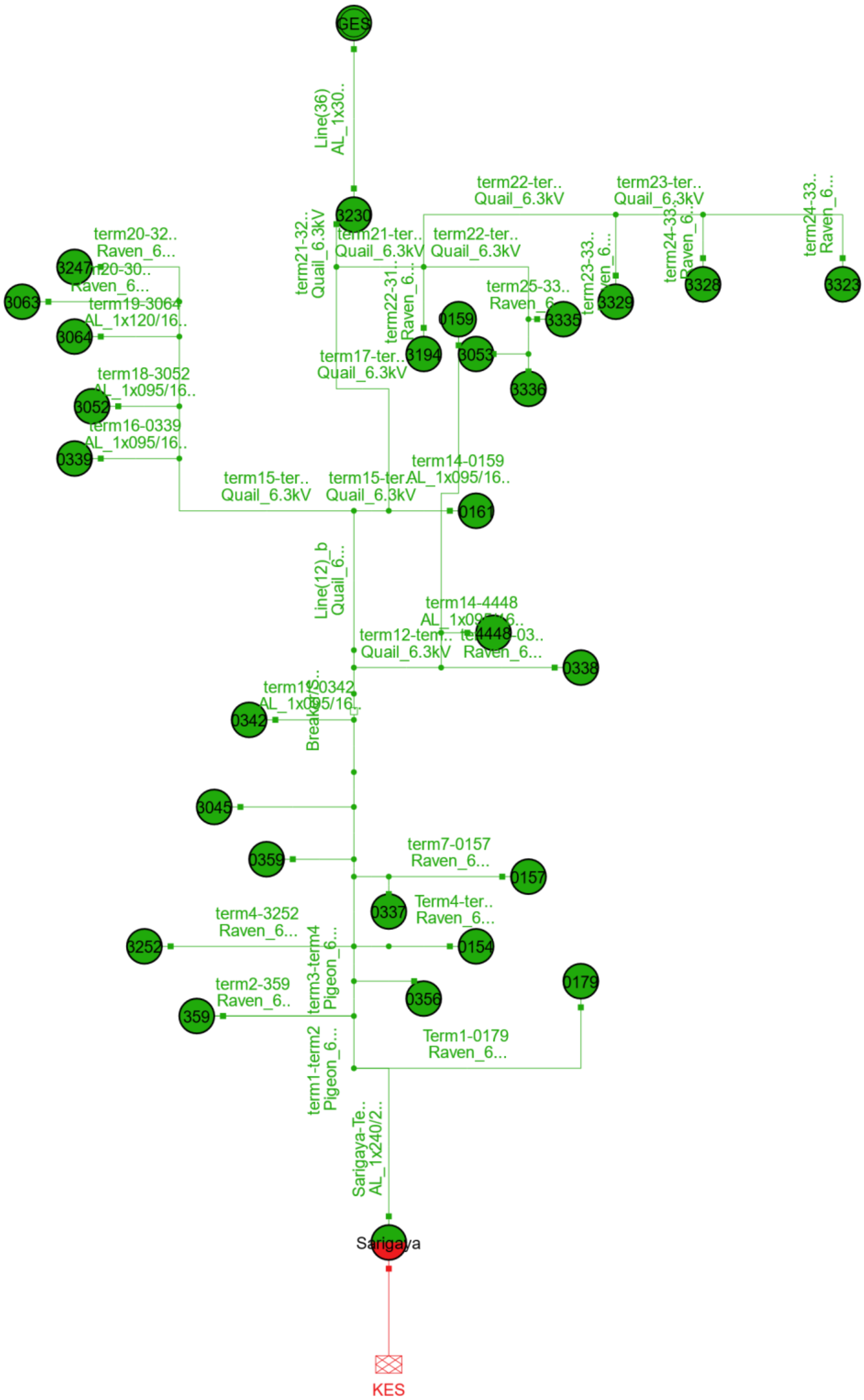
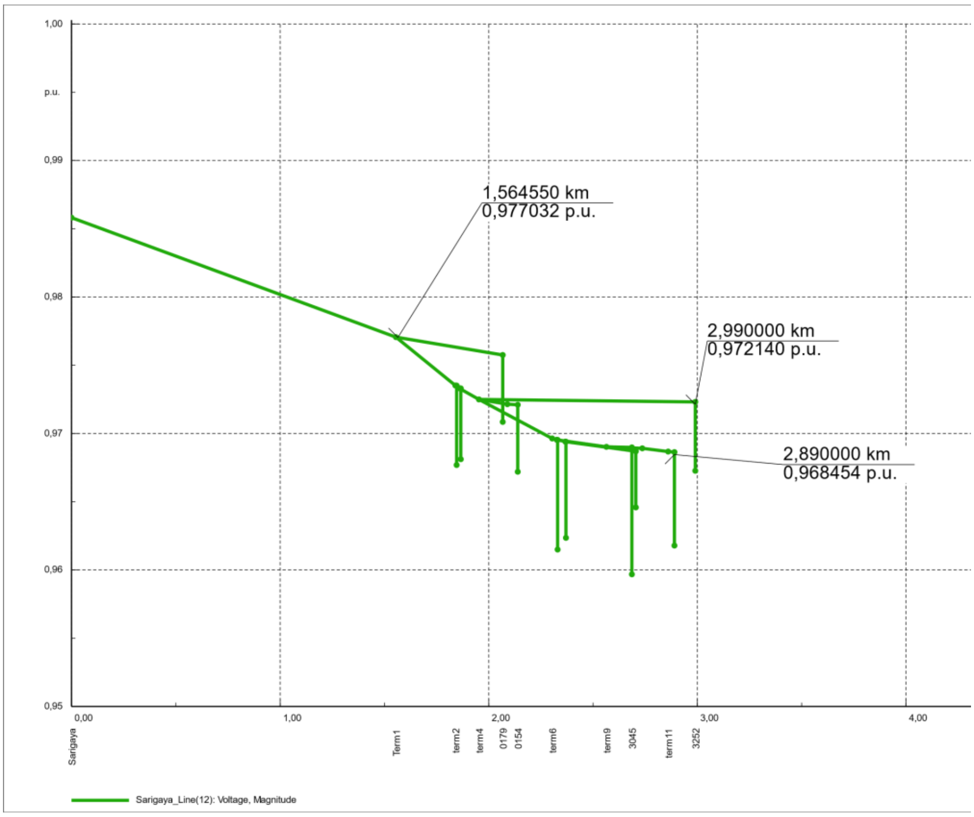


Fig. 11. The model of the distribution network for the current settled regime with the integration of green energy (wind, solar) sources.

Table 8 and Fig. 12 present the voltage values and corresponding profile at the nodes of the 6/0.4 kV distribution network with the integration of green energy sources.

Table 8. The voltage values at the nodes in the normal regime of the scheme with the integration of green energy sources.

Name	Feeders	Network	U_{nom}, kV	U_{nom}, p.u.	U, kV	U, dig
BB	Single Busbar	Sariqaya	6,0	1,000	6,0	0,0
BB	3230	Sariqaya	6,0	0,998	6,0	-0,1
BB	3194	Sariqaya	6,0	0,997	6,0	-0,1
BB	3329	Sariqaya	6,0	0,996	6,0	-0,1
BB	3328	Sariqaya	6,0	0,996	6,0	-0,1
BB	3323	Sariqaya	6,0	0,996	6,0	-0,1
BB	3335	Sariqaya	6,0	0,996	6,0	-0,1
BB	3053	Sariqaya	6,0	0,996	6,0	-0,1
BB	3336	Sariqaya	6,0	0,996	6,0	-0,1
BB	Sarigaya	Sariqaya	6,0	0,986	5,9	28,5
BB	0161	Sariqaya	6,0	0,985	5,9	-0,4
BB	0339	Sariqaya	6,0	0,985	5,9	-0,4
BB	3052	Sariqaya	6,0	0,984	5,9	-0,4
BB	3064	Sariqaya	6,0	0,984	5,9	-0,4
BB	3063	Sariqaya	6,0	0,983	5,9	-0,4
BB	3247	Sariqaya	6,0	0,983	5,9	-0,4
BB	4448	Sariqaya	6,0	0,983	5,9	-0,5
BB	0159	Sariqaya	6,0	0,983	5,9	-0,5
BB	0338	Sariqaya	6,0	0,982	5,9	-0,5
BB	0179	Sariqaya	6,0	0,976	5,9	28,2
BB	359	Sariqaya	6,0	0,974	5,8	28,1
BB	0356	Sariqaya	6,0	0,973	5,8	28,1
BB	3252	Sariqaya	6,0	0,972	5,8	28,0
BB	0154	Sariqaya	6,0	0,972	5,8	28,0
BB	0359	Sariqaya	6,0	0,970	5,8	28,0
BB	0337	Sariqaya	6,0	0,969	5,8	28,0
BB	3045	Sariqaya	6,0	0,969	5,8	27,9
BB	0157	Sariqaya	6,0	0,969	5,8	27,9
BB	0342	Sariqaya	6,0	0,969	5,8	27,9



a)

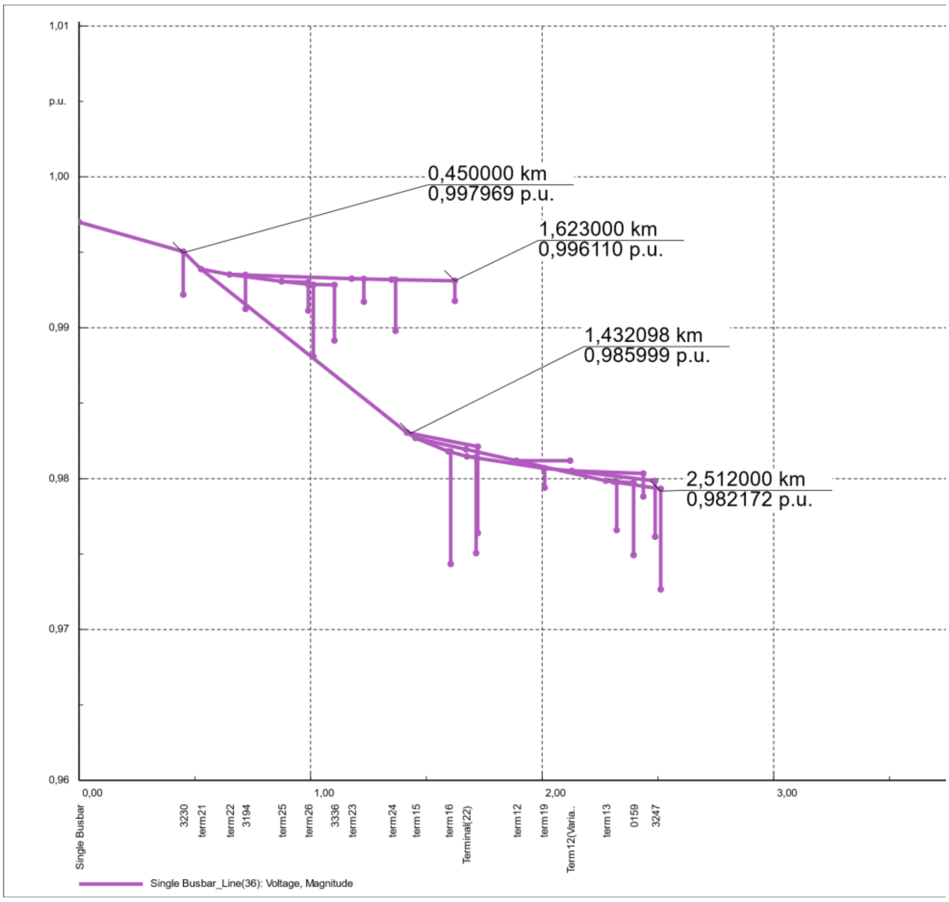


Fig. 12. Voltage profile with the integration of green energy sources

According to Table 8 and Figure 12, the voltage values at the nodes are within the $(0{,}969-1{,}0)\cdot U_{nom}$ accepted normal allowable limits. Table 9 provides the loading rates of the feeders under normal loading conditions. As seen, in this case, the loading reaches a maximum of 37%.

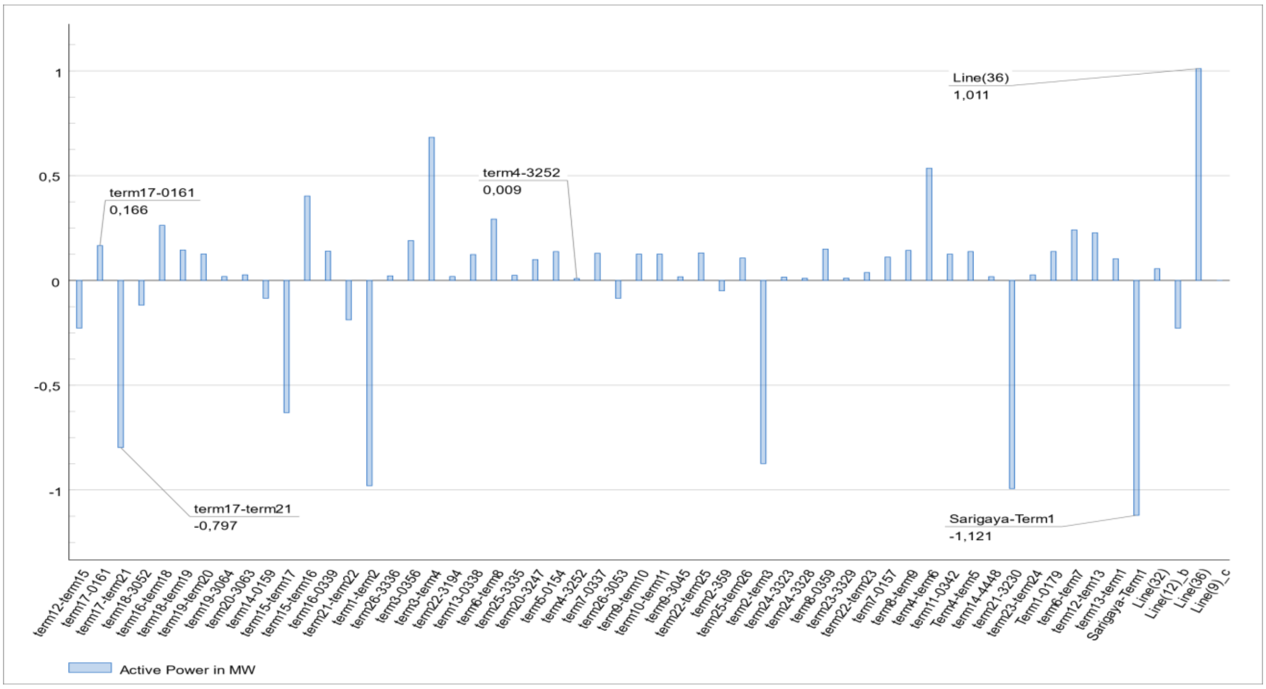
Table 9. Loading rates of the feeders under normal conditions

Name	**Network**	**Loading, %**	**Current, kA**
term21-3230	Sariqaya	37,0	0,102
term1-term2	Sariqaya	32,3	0,102
term17-term21	Sariqaya	29,9	0,082
term2-term3	Sariqaya	28,8	0,091
term15-term17	Sariqaya	23,7	0,065
term3-term4	Sariqaya	22,5	0,071
Sarigaya-Term1	Sariqaya	21,9	0,116
term4-term6	Sariqaya	20,2	0,056
Line(36)	Sariqaya	20,0	0,103
term15-term16	Sariqaya	15,2	0,042
term6-term8	Sariqaya	11,1	0,030
term16-term18	Sariqaya	10,0	0,028
term6-term7	Sariqaya	9,2	0,025
term12-tem13	Sariqaya	8,5	0,023
term12-term15	Sariqaya	8,5	0,023
Line(12)_b	Sariqaya	8,5	0,023
term17-0161	Sariqaya	7,1	0,017
term21-term22	Sariqaya	7,0	0,019
Term4-term5	Sariqaya	6,0	0,014
Term1-0179	Sariqaya	6,0	0,014
term3-0356	Sariqaya	5,9	0,020
term18-term19	Sariqaya	5,7	0,016
term8-0359	Sariqaya	5,4	0,016
term8-term9	Sariqaya	5,4	0,015
term13-0338	Sariqaya	5,3	0,013
term16-0339	Sariqaya	5,0	0,014

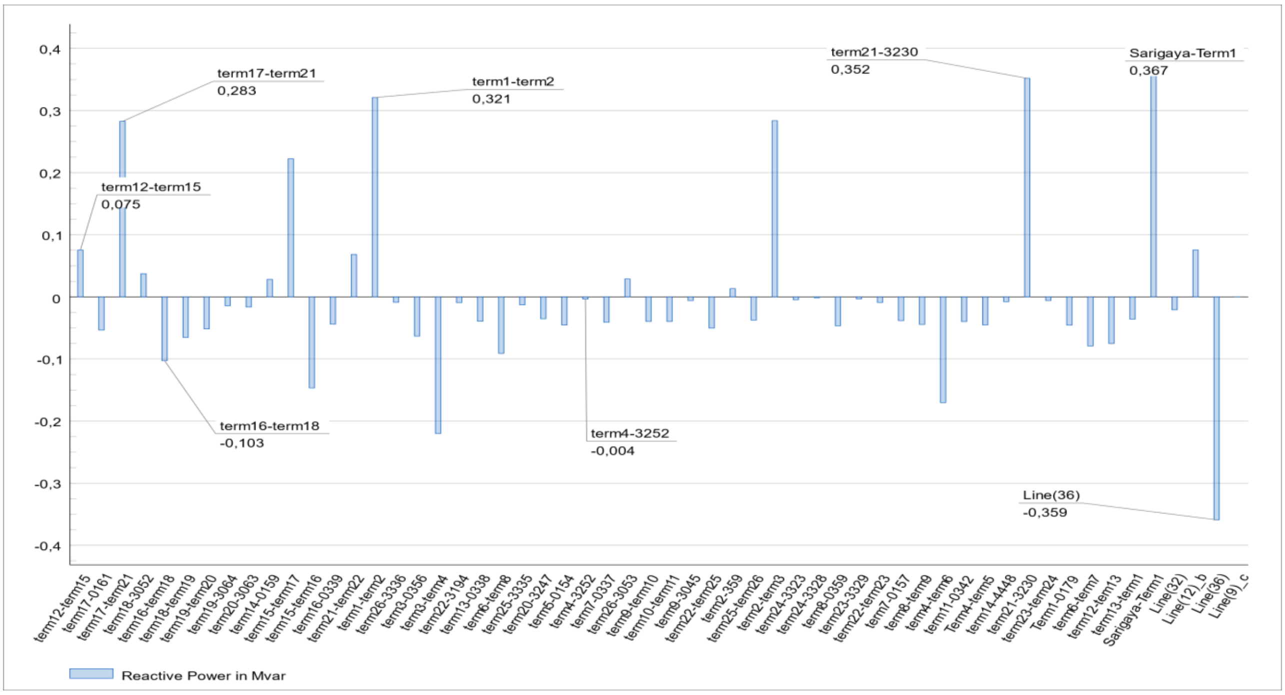
Fig. 13 depicts the diagrams of active (a) and reactive (b) powers at the demand nodes of the distribution network with the presence of green sources. It can be observed from Figure 13 that the reactive power factor ranges from 0.112 to 0.465 in the examined regime, and appropriate measures are required to compensate for the reactive power.

Table 10 and Fig. 14 provide the voltage values and profile at the demand buses for a 50% overload condition with the integration of wind and solar energy sources into the distribution network. As shown in the voltage profile and values, the values are within the $(0{,}941-1{,}0)\cdot U_{nom}$ interval and can be considered acceptable.

Table 11 and Fig. 15 depict the loadings of feeder lines and the active and reactive power demands of the demand nodes, respectively. In the examined case, the feeder loadings range from 13.1% to 67.8%.



a)



b)

Fig. 13. Active (a) and reactive (b) power demands of the network with green sources

Table 10. Voltage values under 50% loading condition

Name	Feeders	Network	U_{nom}, kV	U, p.u.	U, kV	U, dig
BB(3)	Sarigaya	Sariqaya	35,0	1,000	35,0	0,0

BB	Single Busbar	Sariqaya	6,0	1,000	6,0	0,0
BB	3230	Sariqaya	6,0	0,996	6,0	-0,2
BB	3194	Sariqaya	6,0	0,994	6,0	-0,2
BB	3329	Sariqaya	6,0	0,993	6,0	-0,3
BB	3328	Sariqaya	6,0	0,993	6,0	-0,3
BB	3323	Sariqaya	6,0	0,993	6,0	-0,3
BB	3335	Sariqaya	6,0	0,993	6,0	-0,3
BB	3053	Sariqaya	6,0	0,993	6,0	-0,3
BB	3336	Sariqaya	6,0	0,993	6,0	-0,3
BB	Sarigaya	Sariqaya	6,0	0,974	5,8	27,2
BB	0161	Sariqaya	6,0	0,973	5,8	-0,8
BB	0339	Sariqaya	6,0	0,972	5,8	-0,8
BB	3052	Sariqaya	6,0	0,972	5,8	-0,8
BB	3064	Sariqaya	6,0	0,970	5,8	-0,8
BB	3063	Sariqaya	6,0	0,970	5,8	-0,8
BB	3247	Sariqaya	6,0	0,969	5,8	-0,9
BB	4448	Sariqaya	6,0	0,969	5,8	-0,9
BB	0159	Sariqaya	6,0	0,969	5,8	-0,9
BB	0338	Sariqaya	6,0	0,968	5,8	-0,9
BB	0179	Sariqaya	6,0	0,955	5,7	26,5
BB	3259	Sariqaya	6,0	0,951	5,7	26,3
BB	0356	Sariqaya	6,0	0,950	5,7	26,3
BB	3252	Sariqaya	6,0	0,948	5,7	26,3
BB	0154	Sariqaya	6,0	0,948	5,7	26,3
BB	0359	Sariqaya	6,0	0,943	5,7	26,1
BB	0337	Sariqaya	6,0	0,943	5,7	26,1
BB	3045	Sariqaya	6,0	0,942	5,7	26,1
BB	0157	Sariqaya	6,0	0,942	5,6	26,1
BB	0342	Sariqaya	6,0	0,941	5,6	26,1

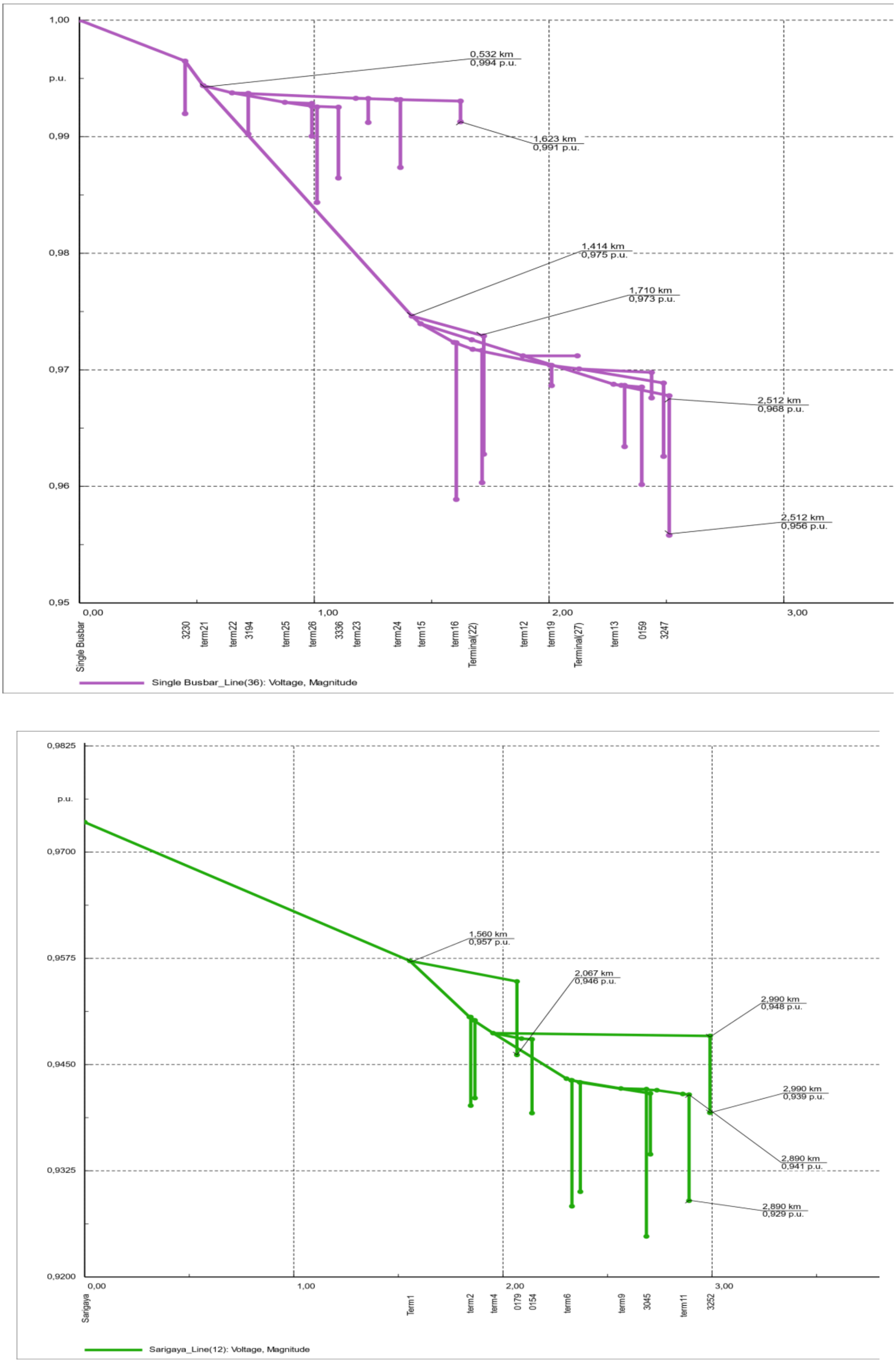
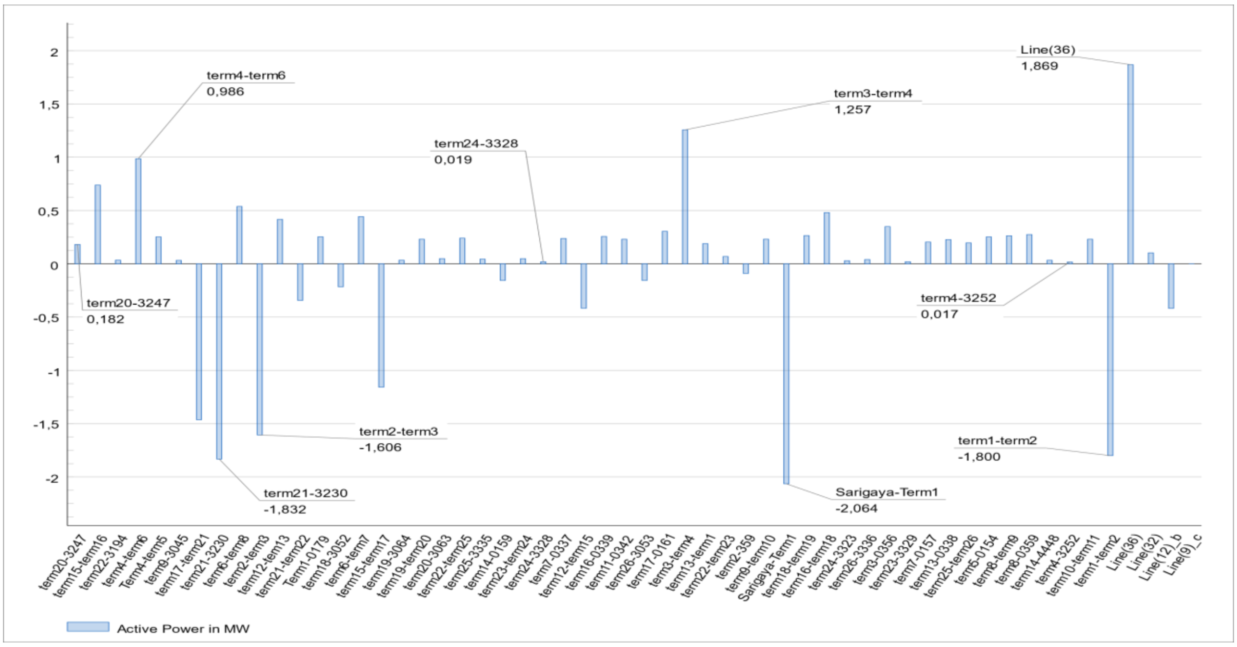


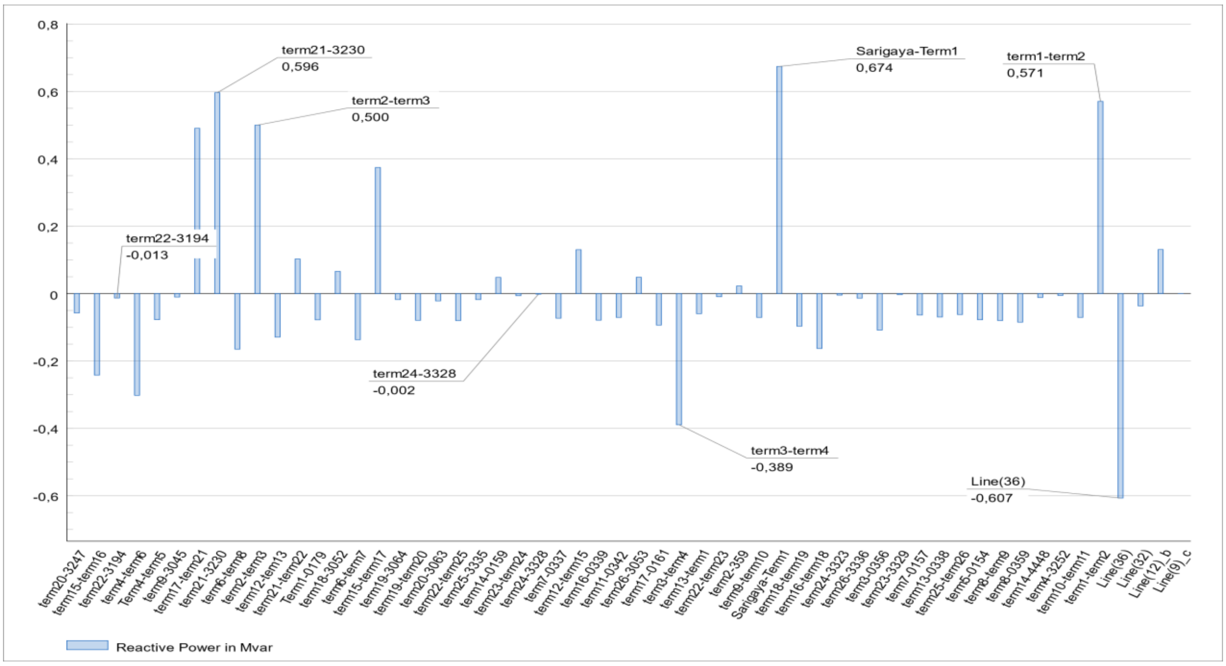
Fig. 14. Voltage profile with the implementation of green sources

Table 14. Loadings of the network feeders

Name	Network	Loading, %	Current, kV
term21-3230	Sariqaya	67,8	0,186
term1-term2	Sariqaya	60,6	0,191
term17-term21	Sariqaya	55,2	0,152
term2-term3	Sariqaya	54,1	0,170
term15-term17	Sariqaya	43,7	0,120
term3-term4	Sariqaya	42,3	0,133
Sarigaya-Term1	Sariqaya	41,0	0,218
term4-term6	Sariqaya	38,1	0,105
Line(36)	Sariqaya	36,7	0,189
term15-term16	Sariqaya	27,9	0,077
term6-term8	Sariqaya	20,9	0,057
term16-term18	Sariqaya	18,3	0,050
term6-term7	Sariqaya	17,2	0,047
term12-tem13	Sariqaya	15,8	0,043
term12-term15	Sariqaya	15,8	0,043
Line(12)_b	Sariqaya	15,8	0,043
term17-0161	Sariqaya	13,1	0,032



a)



b)

Fig. 15. Diagrams of active (a) and reactive (b) demands under 50% overload condition with the application of green energy sources

Fig. 15 shows that during a 50% overload condition with the integration of green energy sources into the distribution network, the reactive power factor values range from 0.127 to 0.403. This indicates that, in some nodes, appropriate measures are required to compensate for the reactive power.

4. Comparative analysis of the modeling report results

"The comparative analysis results of the distribution network for the aforementioned operational scheme solutions are provided in Table 15. The comparative analysis of the existing and proposed schemes shows that the proposed alternatives are effective in addressing the issues present in the existing scheme, such as voltage drop (ΔU), component overloads, and ensuring that the reactive power factor values are within allowable intervals. Specifically, the analysis of the comparative operational reports for transitioning from the current 35/0.4 kV voltage level and implementing green energy technologies indicates the following improvements:

- In the first case, switching to the proposed alternatives reduced the voltage drop from 13% to 3.5%, the loading percentage on the lines decreased from 168% to 45%, and the critical load capacity significantly increased. Power loss decreased from 106.73 kW to 79.54 kW, a reduction of 25.5%.
- In the second case, these indicators improved with the loading percentage decreasing from 168% to 67.8%, the voltage drop reduced from 13% to 2%, and power loss decreased from 106.73 kW to 48.82 kW, a reduction of 54.2%.

Similar indicators were analyzed for the 50% and 80% overload conditions, and comparable results were obtained.

Thus, the analysis of the distribution network's operational modes highlights the need for its improvement or reconstruction. Therefore, appropriate measures must be selected and implemented

to ensure that consumers are supplied with reliable and high-quality electricity. It is important to note that since the network is located in the Absheron region, and considering the effectiveness of wind and solar sources as well as the analysis results, it is recommended to favor the third option, i.e., the implementation of green energy technologies.

Table 15. Comparative report results of the variants

Parameters	**Determined mode**	**50% Overload**	**80% Overload**
Existing scheme			
ΔU, %	$5{,}6 \div 6\ kV$	$5{,}2 \div 5{,}9\ kV$	$5{,}0 \div 5{,}7\ kV$
ΔP, kW	106,73	366,67	637,27
$tg\varphi$	$0{,}185 \div 0{,}684$	$0{,}105 \div 0{,}407$	$0{,}082 \div 0{,}415$
Transition to the 35/0.4 kV voltage level			
ΔU, %	$34{,}2 \div 34{,}9\ kV$	$33{,}0 \div 34{,}6\ kV$	$34{,}5 \div 32{,}2 kV$
ΔP, kW	79,54	310,87	565,26
$tg\varphi$	$0{,}296 \div 0{,}388$	$0{,}323 \div 0{,}406$	$0{,}348 \div 0{,}429$
Implementation of green energy technologies			
ΔU, %	$5{,}8 \div 6\ kV$	$5{,}6 \div 5{,}9\ kV$	$5{,}0 \div 5{,}7\ kV$
ΔP, kW	48,82	133,63	608,41
$tg\varphi$	$0{,}14 \div 0{,}608$	$0{,}12 \div 0{,}445$	$0{,}105 \div 0{,}402$

CONCLUSION

1. An analysis of the capabilities of various software tools for simulating and analyzing the operational modes of distribution electrical networks has been conducted. It has been determined that DIgSILENT PowerFactory is the most effective model, providing visualization and real-time research capabilities through its interface modules. The proposed research methodology in this study utilized this software suite.

2. A mathematical model based on the maximum voltage drop in the feeder line has been developed for analyzing the operational modes of distribution electrical networks. This model allows for the consideration of active and reactive injections based on green technologies within the network.

3. The investigation of the Novkhani-1 distribution network, fed by the Sarıqaya substation of "Azərişıq" OJSC, using the developed mathematical model and software module has shown that the loadings of most 6 kV feeder lines exceed allowable values, with high voltage drops and power losses. These conditions confirm a significant probability of failures in the network. Consequently, it is necessary to improve the existing network or redesign and replan its topology.

4. To address the problems arising during loading and enhance the operational efficiency of the distribution network, it is proposed to either transition to the 35/0.4 kV voltage level or integrate green energy sources (wind and solar) into the network. These measures are expected to improve the efficiency of the distribution network. Additional technical and economic justifications are required for the selection of the proposed options.

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